UNDERSTANDING THE HUMAN FACTOR OF THE ENERGY TRANSITION: MECHANISMS UNDERLYING ENERGY-RELEVANT DECISIONS AND BEHAVIORS

EDITED BY: Tobias Brosch, David Sander and Martin K. Patel

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UNDERSTANDING THE HUMAN FACTOR OF THE ENERGY TRANSITION: MECHANISMS UNDERLYING ENERGY-RELEVANT DECISIONS AND BEHAVIORS

Topic Editors:
Tobias Brosch, University of Geneva, Switzerland
David Sander, University of Geneva, Switzerland
Martin K. Patel, University of Geneva, Switzerland

Solar panels (image taken from pixabay.com).

An increasing number of countries are shifting toward sustainable energy economies, emphasizing the use of renewable energy sources, increases in energy efficiency and the abatement of greenhouse gas emissions. The success of such an energy transition will depend not only on the development of new energy technologies, but also on major changes in the patterns of individual energy-related decisions and behaviors resulting in substantial reductions in energy demand. Consequently, the behavioral sciences can make important contributions to the energy transition by increasing our understanding of the multiple factors and mechanisms that underlie individual as well as group-based decisions and behaviors in the energy domain and by creating a basis for systematic interventions that reduce energy usage.

Many different types of relevant behaviors and decisions need to be considered in this context, including decisions to invest in energy-efficient household equipment, adjustments of energy-critical habits related to heating, eating, or mode of transportation, and participation in the political discourse related to questions of energy. An integration of the expertise of the different disciplines of the behavioral sciences is thus needed to comprehensively investigate the impact of the different drivers and barriers that may determine energy-related decisions and behaviors, including economic factors such as price level, social factors such as norms, communication patterns and social learning processes, and individual factors such as values, attitudes, beliefs, heuristics, affective biases and emotions.

The potential impact of these factors on the success of the energy transition is considerable: for example, a recent projection of the energy demand in Switzerland until 2050 has estimated the reduction potential related to psychological and sociological factors between 0% and 30%, depending on which behavioral changes will be implemented in society. Increased research efforts from the behavioral sciences are required to ensure that the full reduction potential can be achieved. This Research Topic brings together contributions from different disciplines such as psychology, affective science, behavioral economics, economics, sociology, consumer behavior, business science, sociology, and political science, that improve our understanding of the many factors underlying decision-making and behavior in the energy domain, and contribute to the development of targeted interventions that aim at reducing energy demand based on these factors.

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EDITORIAL
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Editorial: Behavioral Insights for a Sustainable Energy Transition

Tobias Brosch[1], David Sander[1] and Martin K. Patel[2]*

[1] *Department of Psychology, Swiss Center for Affective Sciences, University of Geneva, Geneva, Switzerland,*
[2] *Energy Group, Institute for Environmental Sciences and Forel Institute, University of Geneva, Geneva, Switzerland*

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The Editorial on the Research Topic

Understanding the human factor of the energy transition: Mechanisms underlying energy-relevant decisions and behaviors

In December 2015, 195 countries adopted the Paris Agreement, which aims at a substantial reduction of greenhouse gas emissions to keep the increase in global average temperature to 2°C or less. The successful implementation of this global energy transition does not only depend on the development of new energy technologies, but also requires major changes in the patterns of individual energy-related choices and behaviors. The behavioral sciences can thus make important contributions to the energy transition by providing insights into the factors and mechanisms that underlie these behaviors.

To this end, three main challenges need to be addressed: (1) to investigate and systematize the factors that influence energy-relevant choices and behaviors; (2) based on these insights, to develop and test interventions that promote more sustainable behavior; and (3) given that individual behavior takes place in a political and economic context, to integrate behavioral insights into the context of these larger systems. These challenges are taken up in the contributions of this research topic, which cover the fields of psychology, affective science, behavioral economics, economics, sociology, consumer behavior, business science, sociology, and political science. Here, we give an overview of the contributions and discuss some implications and recommendations for a successful energy transition.

UNDERSTANDING THE DETERMINANTS OF SUSTAINABLE BEHAVIOR

To successfully promote more sustainable choices and behaviors, we first need to understand their determining factors. Steg et al. propose a framework of the different behaviors that are relevant for sustainability at the household level as well as their determinants and potential intervention strategies. They emphasize the need to develop integrative approaches that explain a wide range of energy-relevant behaviors. Brosch et al. discuss the role of affective factors as influences on energy-relevant decisions. They argue that emotions provide useful information that can lead to better decisions and demonstrate that affective factors can explain energy-relevant behavior above and beyond traditional rational-choice models and value-based approaches. Schubert and Stadelmann analyze the energy efficiency gap from a behavioral economics perspective. They illustrate that consumers may not buy energy-efficient durables – despite the economic advantages these may have in terms of lifetime costs – due to information processing limitations. Skatova et al. demonstrate the important influence of other people's behavior on our choices using an experimental collective-risk game that simulates energy consumption of an interdependent group of participants from the UK. To identify promising targets for sufficiency interventions, Moser et al. analyze the social preferences for energy sufficiency

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Simone Bastianoni, University of Siena, Italy

****Correspondence:***
Tobias Brosch
tobias.brosch@unige.ch

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behaviors across the domains of mobility, heating, and food in a Swiss sample. They show that while participants would, for example, be willing to reduce their living space to conserve energy, they would be very reluctant to give up meat consumption.

The contributions in this section illustrate the importance of going beyond the boundaries of individual disciplines to integrate the multiple factors that influence energy-relevant choices and behaviors. Aspects related to information processing, such as available information, processing biases, and heuristics, affective-motivational factors, such as attitudes, values, and emotions, and social influences, such as social norms and status considerations, all are critical determinants of sustainable behavior. Moreover, these factors interact with the choice context, e.g., specific aspects of the behavior/technology in question, available options, potential incentives, and barriers. Thus, any understanding of energy-relevant behavior needs to be based on a consideration of the interaction of personal and situational factors.

DEVELOPING AND TESTING INTERVENTION STRATEGIES TO PROMOTE SUSTAINABLE BEHAVIOR

A thorough understanding of the factors influencing sustainable behavior allows the development of effective intervention strategies. Shalev discusses how insights from social and motivational psychology can be leveraged to motivate individuals to take action against climate change. She emphasizes the importance of integrating sustainable behavior into a goal system that also includes other concerns regarding domains such as health, economy, and education. Sintov and Schultz demonstrate how behavioral insights can be helpful in the context of smart grid systems, which are used by energy utilities to interact with their consumers in real time. Using examples such as demand response programs, time-of-use pricing, and energy feedback, they illustrate how energy utilities can increase the engagement of their end users. Graffeo et al. test a nudge-like intervention based on social norms on a sample of university students from Jerusalem. Varying the degree of information that is revealed about the source of a social norm, they show that the most efficient norms come from sources that are identified as “living in the same neighborhood as the participant,” but that the provision of further identifying information (such as the name and a photo of the source) leads to a decrease of the social influence. Klonek and Kauffeld illustrate the potential of *motivational interviewing*, a persuasion technique that aims at reducing resistance to behavior change in the sustainability domain. Moreover, they provide training materials that can be used for interventions in organizational settings in the supplementary materials. Pahl et al. discuss their experiences from the eViz project, an intervention project that explores the potential of energy visualizations – thermal images visualizing heat escaping from buildings – to motivate people to invest in energy efficiency measures. They show that energy visualizations can attract attention, elicit affective reactions, and furthermore lead to reductions in energy use as well as increased investments in isolation measures.

The contributions in this section illustrate the enormous potential of applying behavioral insights to the context of sustainability interventions. They help understand why some previously used intervention instruments (e.g., purely financial incentives and information provision) may not function optimally due to bounded rationality. More importantly, they point out ways in which better intervention strategies can be developed by taking into account limited information processing (e.g., better energy label design) and the enormous impact of affective motivational and social factors (e.g., interventions based on affective responses or social influence).

BEHAVIORAL INSIGHTS IN THE CONTEXT OF MARKETS AND POLITICAL SYSTEMS

Energy-relevant choices and behaviors do not take place in isolation, but in the context of markets and political systems, which interact with the more proximal determinants of decision making as discussed above. It is thus important to consider behavioral insights in the context of these larger systems. Krysiak and Weigt review economic models of energy markets with respect to their representation of consumer behavior. They identify gaps in existing approaches and outline possibilities to integrate more detailed and realistic representations of human behavior into these models. Burger et al. merge theoretical perspectives from multiple disciplines into a framework of energy-related consumption behavior with the “situated individual,” an individual living in a complex social environment, at its center. The framework comprises multiple levels of behavioral influences as well as potential interventions at the economic and political level and promises to be a useful tool for guiding future interdisciplinary research.

OUTLOOK

Developing a more sustainable energy use is one of the most pressing tasks facing our planet and its inhabitants. The research topic illustrates the important contributions the behavioral and social sciences can make by providing insights into the mechanisms that underlie our decisions and behaviors. The increasing integration of theoretical and disciplinary perspectives that is illustrated in the contributions assembled here is a welcome development that will result in a more complete toolbox of intervention strategies, contributing to a sustainable energy transition.

AUTHOR CONTRIBUTIONS

All authors listed have made substantial, direct, and intellectual contribution to the work and approved it for publication.

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REVIEW
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Understanding the human dimensions of a sustainable energy transition

Linda Steg, Goda Perlaviciute and Ellen van der Werff*

Department of Psychology, Faculty of Behavioural and Social Sciences, University of Groningen, Groningen, Netherlands

Global climate change threatens the health, economic prospects, and basic food and water sources of people. A wide range of changes in household energy behavior is needed to realize a sustainable energy transition. We propose a general framework to understand and encourage sustainable energy behaviors, comprising four key issues. First, we need to identify which behaviors need to be changed. A sustainable energy transition involves changes in a wide range of energy behaviors, including the adoption of sustainable energy sources and energy-efficient technology, investments in energy efficiency measures in buildings, and changes in direct and indirect energy use behavior. Second, we need to understand which factors underlie these different types of sustainable energy behaviors. We discuss three main factors that influence sustainable energy behaviors: knowledge, motivations, and contextual factors. Third, we need to test the effects of interventions aimed to promote sustainable energy behaviors. Interventions can be aimed at changing the actual costs and benefits of behavior, or at changing people's perceptions and evaluations of different costs and benefits of behavioral options. Fourth, it is important to understand which factors affect the acceptability of energy policies and energy systems changes. We discuss important findings from psychological studies on these four topics, and propose a research agenda to further explore these topics. We emphasize the need of an integrated approach in studying the human dimensions of a sustainable energy transition that increases our understanding of which general factors affect a wide range of energy behaviors as well as the acceptability of different energy policies and energy system changes.

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Edited by:
Tobias Brosch, University of Geneva, Switzerland

Reviewed by:
Stefanie L. Hille, University of St. Gallen, Switzerland
Thomas Dietz, Michigan State University, USA

****Correspondence:***
Linda Steg, Department of Psychology, Faculty of Behavioural and Social Sciences, University of Groningen, Grote Kruisstraat 2/I, 9712 TS Groningen, Netherlands
e.m.steg@rug.nl

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Introduction

Global climate change poses a major threat to the health, economic prospects, and basic food and water sources of billions of people (IPCC, 2014). Negative effects of global climate change are already occurring, such as extreme weather events and reductions in global food supply (IPCC, 2014). Future effects will be even more severe. Global climate change is caused by the emission of greenhouse gasses, which have steadily increased by about 1.5 times between 1990 and 2008 (Boden et al., 2012). Emissions are likely to further increase due to an increasing world population and economic growth (Kharas, 2010; Gerland et al., 2014). CO_2 is the most important greenhouse gas, responsible for about 84% of the total emissions of greenhouse gasses (EPA, 2004). After remaining at stable levels for the past 1000 years at about 280 ppm, atmospheric concentrations of CO_2 are now above 400 ppm (e.g., Mauna Loa Observatory, 2015). Global climate change and environmental decline are largely caused by human behavior and can thus be altered when people more consistently engage in sustainable energy behavior (Dietz et al., 2009; Pawlik and Steg, 2013; IPCC, 2014). The main human activity that emits CO_2 is the combustion of fossil fuels for energy and transportation. For example, households are responsible for 26% of direct energy consumption in Europe by using electricity and gas for, among others, space heating, water heating, and the use of appliances (Eurostat, 2014). This figure is even higher when we also consider energy use for private transportation (32% of all energy is consumed for transportation) and embodied energy use, that is, the energy needed to produce, transport, and dispose of goods and services that households consume. For this reason, we focus on household energy behavior in this paper.

Given the urgency of combating anthropogenic climate change, and the fundamental changes needed to realize a sustainable energy transition, substantial modification of a wide range of household energy behavior is needed. These include the adoption of sustainable energy sources and technologies, the adoption of energy efficiency measures in buildings, the adoption of energy-efficient appliances, and changing user behavior to reduce total energy demand and to match energy demand to available supply of (renewable) energy carriers. Achieving these wide-scale changes in behavior requires a prominent role of social scientists in understanding how to motivate and enable people to actively contribute to a sustainable energy transition (ISSC and UNESCO, 2013; Hackmann et al., 2014; Sovacool, 2014; Weaver et al., 2014). Social scientists can study which factors cause sustainable and unsustainable energy behavior, and examine how these factors can be addressed in energy policy and energy system changes (see also Dietz et al., 2013). Besides, social scientists can study which factors determine the effectiveness and acceptability of energy system changes and policies aimed at promoting a sustainable energy transition (see also Stern, 2014).

In this paper, we review the contribution of social and environmental psychology in understanding and promoting sustainable energy behavior by individuals and households. We propose a general framework, comprising four key issues:

(1) identification and measurement of energy behaviors to be changed,
(2) examination of the main factors underlying energy behavior, including the adoption of sustainable energy resources and energy-efficient technology, investments in energy efficiency measures in buildings, and user behavior,
(3) designing and testing interventions to change energy behavior as to reduce CO_2 emissions by households, including information, financial incentives, regulations and technological changes,
(4) studying factors underlying public acceptability of interventions and changes in energy systems.

We discuss key findings from psychological studies on these four topics, and propose a research agenda for further exploration of these topics. In doing so, we will demonstrate that many studies follow a narrow approach, by studying specific antecedents of single energy behaviors or effects and acceptability of specific policies. We emphasize the need of an integrated approach in studying the human dimensions of a sustainable energy problems that increases our understanding of which general factors affect a wide range of energy behaviors as well as the acceptability of different energy policies and energy system changes. We elaborate on this issue in the Discussion section.

Which Behavior Changes are Needed to Promote a Sustainable Energy Transition?

A sustainable energy transition implies that future energy systems will more strongly rely on renewable energy sources, such as solar or wind energy. Hence, to realize a sustainable energy transition, we need to understand to what extent and under which conditions individuals are willing to accept and adopt renewable energy sources. Besides, to enhance the efficiency of sustainable energy systems and to meet energy demands of individuals and households across the world, total energy demand needs to be reduced, at least in developed countries. For this purpose, individuals can invest in energy efficiency, such as refurbishment of houses and adoption of energy-efficient appliances. Also, they can change their daily energy behaviors, such as reducing thermostat settings or showering time. In addition, people could refrain from certain actions to reduce energy demand (Huber, 2000). Moreover, given that the production of energy from renewable resources may strongly vary with weather conditions, renewables are not always readily available. Hence, individuals may need to balance their energy demand to the available supply of energy produced from renewable resources. Balancing energy demand and supply can be realized by shifting energy use in time, either autonomously or by installing technologies that automatically switch on or off specific appliances on the basis of the available energy supply. In addition, people could adopt storage technologies such as batteries and electric cars.

From a practical point of view, studies ideally focus on behaviors that have an important impact on total energy use and CO_2 emissions, such as the adoption of renewable energy sources, home insulation, and space heating (Abrahamse et al., 2007; Dietz et al., 2009). Households use energy not only in a direct way, for example by using gas or electricity for cooking and heating, but also in an indirect way (Vringer and Blok, 1995; Kok et al., 2006). Indirect energy use refers to the energy requirement of the production, transportation and disposal of goods and services used by households. In European countries, about half of total household energy use reflects direct energy use, while the other half is related to indirect energy use (Kok et al., 2003; Reinders et al., 2003). Yet, only few studies examined factors underlying behavior related to indirect energy use (Gatersleben et al., 2002; Poortinga et al., 2003; Abrahamse et al., 2007). Environmental scientists have developed various tools for assessing direct and indirect energy use, such as life-cycle analysis, and input-output analysis (e.g., Kok et al., 2006). Although the exact numbers produced by these approaches are still debated and remain a topic of research (e.g., Padgett et al., 2008; Dudley et al., 2014), such tools are useful for identifying behaviors associated with relatively high levels of indirect energy use that can help social scientists to identify high impact behaviors to be studied.

As yet, different types of energy behaviors are typically studied in isolation. For example, studies have examined the adoption of renewable energy sources such as solar or wind energy (see Perlaviciute and Steg, 2014, for a review), subscription to green power tariffs (Tabi et al., 2014), investment in specific energy efficiency technologies such as electric vehicles (Schuitema et al., 2013; Bockarjova and Steg, 2014; Klöckner, 2014; Noppers et al., 2014) or energy efficient light bulbs (Reynolds et al., 2007; Lee et al., 2013), the adoption and use of specific components of smart grids (Sintov and Schultz, 2015), including smart meters (Kaufmann et al., 2013), and specific energy behaviors such as doing your laundry (McCalley and Midden, 2002) or showering (Aronson and O'Leary, 1982–1983). An important question is how these different types of behaviors are related, and how broader lifestyle effects can be realized, including, for example, adoption of renewable energy sources and energy-efficient technologies, changes in everyday energy behavior, investments in refurbishments, and acceptability of energy policy. A key issue here is whether and under which conditions engagement in one type of sustainable energy behavior is likely to spillover to other behaviors, including other types of environmental behavior such as water use and waste handling (Truelove et al., 2014). On the one hand, some studies suggest that engaging in one type of sustainable energy behavior is likely to inhibit other sustainable energy behaviors (referred to as negative spillover, the rebound effect, the Jevons paradox, or moral licensing; Thøgersen and Ölander, 2003; York, 2012; Tiefenbeck et al., 2013). For example, people were likely to increase their energy consumption after reducing their water use (Tiefenbeck et al., 2013), and they were less likely to recycle their waste after buying organic products (Thøgersen and Ölander, 2003). Research suggests that so-called compensatory green beliefs, reflecting the extent to which individuals think that engagement in one sustainable behavior legitimates not acting sustainable in another occasion, may inhibit durable sustainable energy behavior, and hence result in negative spillover effects (Kaklamanou et al., 2015). Yet, literature suggests that such negative spillover effects may be small (Gillingham et al., 2013; Blanken et al., 2015) and generally not fully offset the efficiency gains of the initial measure (Barker et al., 2009; Frondel et al., 2012). Still, little is known about how we can prevent that sustainable energy actions lead to negative spillover or "rebound" effects.

On the other hand, several studies have found positive spillover effects (Thøgersen and Ölander, 2003; Lanzini and Thøgersen, 2014). For example, people who recycled were more likely to buy organic food and use environmentally-friendly modes of transport one and two years later (Thøgersen and Ölander, 2003). Also, an increase in green buying following an intervention promoted subsequent recycling, the use of public transport, car-pooling, printing on both sides, saving water, and switching off lights (Lanzini and Thøgersen, 2014). Research suggests that such positive spillover effects are more likely when people relate the initial sustainable energy behaviors to themselves, thereby strengthening their environmental or energy-saving self-identity (Van der Werff et al., 2013, 2014a,b). More particularly, when people realize they engaged in sustainable energy behaviors (or more generally pro-environmental behaviors), they are more likely to see themselves as a pro-environmental person, which motivates them to act in line with this identity in subsequent situations. This finding is in line with self-perception theory (Bem, 1972). The question remains, however, how durable positive spillover effects are, as long-term effects have typically not been considered. Also, only few studies have tested causality regarding spillover effects. We come back to this issue in the Discussion section.

Factors Underlying Energy Behavior

Behavioral interventions aimed to encourage sustainable energy use will be more successful if they target important antecedents of behavior, and remove significant barriers to change. Hence, it is important to examine which factors affect the likelihood that people engage in behaviors that promote a sustainable energy transition. In this section, we discuss three key factors that may influence sustainable energy behavior: people need to be aware of the need for and possible ways to contribute to a sustainable energy transition, they should be motivated to engage in the relevant behaviors, and they need to be able to do so.

Knowledge

In general, people are well aware of the problems related to household energy use, and are concerned about these problems (Abrahamse, 2007). Yet, knowledge on the causes and consequences of climate change, as well as on the impact of human behavior on climate change is not always accurate. For example, there is still confusion about the processes that cause global warming (e.g., Bord et al., 2000; Whitmarsh et al., 2011). Also, only about half of the people know that if today's greenhouse content in the atmosphere would be stabilized, the climate would still warm for at least another 100 years (Tobler et al., 2012). Climate change knowledge is higher among those with a higher level of education, although correlations were not strong (Tobler et al., 2012).

People have a limited understanding of the extent to which their behavior contributes to climate change. For example, only a limited number of people know that heating and cooling homes contribute to global warming (Bord et al., 2000). People have misperceptions regarding the relative contribution of different activities and processes causing global warming: generally people identify the causes of global warming more with distant activities, such as industry, than with their own actions (Whitmarsh et al., 2011).

Besides, people's perceptions of the energy use through their own behaviors is not always accurate. This implies that they may not accurately judge which behavior changes are effective to reduce energy consumption and related CO_2 emissions. People tend to rely on a simple heuristic when assessing the energy use of household appliances, notably the size of appliances. The larger the appliance, the more energy it is believed to use (Baird and Brier, 1981; Schuitema and Steg, 2005), which is not always true. This may lead to underestimations of the energy use of small appliances, such as chargers, and overestimations of the energy use of large appliances, such as a vacuum cleaner. In addition, people tend to underestimate the energy needed to heat water, which suggests that people are not well aware of the fact that they can save energy by showering or bathing less (Schuitema and Steg, 2005). Also, people think that higher energy savings can be realized via curtailment behaviors, such as turning off lights, than efficiency improvements, such as installing more efficient light bulbs and appliances (Attari et al., 2010), while the opposite is true according to experts. Assessing indirect energy use is even more complicated, as, typically, no information of the "embedded" energy use of products and services is provided. Indeed, people know relatively little about the energy use associated with the production, transportation, and disposal of products (Tobler et al., 2011). For example, they overestimate the environmental benefits of organic production, as well as the environmental harm of packaging and conservation of vegetables. Moreover, when assessing the environmental impact of vegetables, people mainly consider the transportation distance rather than transportation mode (Tobler et al., 2011). Also, many people do not know that meat consumption contributes to global warming through indirect energy use (Whitmarsh et al., 2011).

People may also hold misperceptions about characteristics of different types of energy sources and their effects on the environment. For example, some individuals categorized natural gas as a renewable energy source, most likely due to the connotation of the English word "natural," while only about 55% recognized that biomass is a renewable energy source (Devine-Wright, 2003). Also, people associated bioenergy with fossil fuels due to the involved process of burning materials (Butler et al., 2013). People hold misperceptions about carbon capture and storage technology as well. For example, they associate storing CO_2 with blowing a balloon and hence mistakenly picture CO_2 reservoirs as big underground caverns filled with pure CO_2 (Wallquist et al., 2010).

Knowledge about environmental and climate change problems is related to more concern about these problems, and more positive attitudes toward environmental protections (O'Connor et al., 1999). For example, people who are more knowledgeable about climate change and the causes of climate change are generally more concerned about climate change (Sunblad et al., 2009; Tobler et al., 2012; Guy et al., 2014). People with direct experiences of consequences related to climate change are more concerned about problems related to climate change, and more willing to reduce their energy use (Spence et al., 2011; Akerlof et al., 2013; Rudman et al., 2013). Individuals with right-of-centre political views and those who emphasize individual autonomy rather than collective ties are more likely to reject mainstream climate science knowledge (Kahan et al., 2010; Costa and Kahn, 2013). This is particularly likely when solutions to climate change conflict with one's political ideology, suggesting that rejecting climate change knowledge could be a motivational phenomenon (Campbell and Kay, 2014; see also McCright and Dunlap, 2013). A correlational study in the US revealed that higher levels of science literacy and technical reasoning capacity were not related to increased concern with climate change, suggesting that lack of understanding of the science behind climate change is not the main reason for not taking climate change seriously (Kahan et al., 2012). If anything, science literacy and numeracy led to more polarized attitudes toward climate change that align with people's worldviews, notably hierarchical, individualistic versus egalitarian, communitarian worldviews that are associated with, respectively, relatively low versus high concern with climate change (Kahan et al., 2012; cf. McCright and Dunlap, 2011a,b). The media and public and political debate (e.g., initiated by interest groups) present arguments that nourish views of climate change supporters as well as climate change deniers. In the USA, campaigns have been pursued that deny the seriousness of anthropogenic climate change, primarily emphasizing that scientists disagree about climate change, thereby aiming to create confusion among the public (McCright et al., 2013). The more individuals think that scientists disagree about climate change, the less they believe in global warming and the less they support policies to combat climate change. People with right-wing and conservative political views are more prone to doubt scientific consensus on climate change, whereas people with left-wing and liberal political views and those who participate in environmental movements are more likely to believe that scientists agree on this topic (McCright et al., 2013). At the same time, it was found that specific climate change knowledge attenuates the negative relationship between individualistic ideologies and beliefs about the existence of climate change (Guy et al., 2014).

Knowledge can affect the evaluation of pros and cons of energy alternatives. For example, the more factual knowledge respondents had about hydrogen, the more they perceived it as environmentally-friendly, but also, although to a lesser extent, as unsafe (Molin, 2005). Knowledge is not strongly related to environmental behavior, including energy behavior. Although some studies showed that more environmental knowledge increases the likelihood of pro-environmental and sustainable energy behavior somewhat (Hines et al., 1986/1987; Frick et al., 2004), other studies showed that more knowledge does not encourage pro-environmental and sustainable energy behavior (Schahn and Holzer, 1990; Kollmuss and Agyeman, 2002; Meinhold and Malkus, 2005; Vicente-Molina et al., 2013). Research suggests that different types of knowledge can predict environmental behavior differently. More specifically, only action-related knowledge (i.e., knowing what can be done about environmental problems) and effectiveness knowledge (i.e., knowing about the benefits or effectiveness of pro-environmental actions) predicted environmental behavior, although this was the case in just two out of five sub-samples included in this particular study (Frick et al., 2004). System knowledge (i.e., understanding the natural states of ecosystems and the processes within them) only affected environmental behavior indirectly, via the other two types of knowledge. These findings suggest that although knowledge may be a precondition for pro-environmental and sustainable energy behavior, it is not sufficient to promote such behavior. Notably, knowledge will have limited effects when people are not motivated to engage in sustainable energy behavior, or when they do not feel able to engage in such behaviors. We elaborate on these two factors below.

Motivations

Whether or not people engage in sustainable energy behavior will depend on their motivation to do so. People will be more motivated to engage in sustainable energy behaviors when they evaluate the consequences of such behaviors more favorably, that is, when the behavior has relatively more benefits and less costs. Individuals can base their decisions on the evaluation of individual as well collective consequences of behavior, as we illustrate below. Next, we discuss general motivational factors, notably values, which affect how people evaluate various costs and benefits of specific sustainable energy behaviors.

People are more likely to engage in sustainable energy behavior when they believe such behavior has relative low individual costs and high individual benefits, resulting in overall positive evaluations of the relevant actions. This was found for both direct and indirect energy use. For example, people were more likely to travel by car (Bamberg and Schmidt, 2003), to purchase energy-saving light bulbs, and to consume meat when they evaluated these behaviors more favorably (Harland et al., 1999). Besides instrumental costs and benefits such as prices, time, and comfort, people may also consider affective and social costs and benefits. For example, people are more likely to engage in sustainable energy behaviors when they expect to derive pleasure from such behavior (Smith et al., 1994; Pelletier et al., 1998; Steg, 2005; Carrus et al., 2008; Gatersleben and Steg, 2012), and when they expect that others would approve of it (Harland et al., 1999; Nolan et al., 2008), and when receive information on the sustainable energy behaviours of others (Allcott, 2011). They may also engage in sustainable energy behavior because they expect that the particular behavior enhances their status, particularly when the behavior is somewhat costly, as in this case the behavior signals to others that they have sufficient resources to make altruistic sacrifices (Griskevicius et al., 2010). Similarly, the likelihood of adoption of sustainable innovations such as an electric car and renewable energy systems appeared to be higher when consumers evaluated their symbolic aspects, that is, the extent to which these innovations signal something positive about the owner or user to others and themselves, more favorably (Noppers et al., 2014). Positive symbolic outcomes may thus encourage people to adopt sustainable innovations, even though they still have some instrumental drawbacks, which is often the case in the early introduction phases. In fact, it appears that evaluations of the symbolic aspects of sustainable energy innovations more strongly predict interest in such innovations when people think the innovations have some instrumental drawbacks, probably because these drawbacks increase the signaling function on the relevant behavior (Noppers et al., 2014). Behavior has a larger signaling value for prestige and identity effects when it is somewhat costly. For example, when sustainable energy behavior is very easy, convenient or profitable, it is hard to claim that you engaged in the behavior because you care for others and the environment. Engaging in sustainable energy behavior that is somewhat costly or effortful is more likely to signal that you care about others and the environment (cf. Gneezy et al., 2012).

Some sustainable energy behaviors have clear individual benefits. For example, some people may enjoy cycling more than driving a car, saving energy at home will save money, and driving an electric vehicle may enhance people's status, as described above. However, sustainable energy behaviors oftentimes are somewhat costly, effortful, and less pleasurable. For example, insulating your home or installing solar panels on your roof is a hassle and costs time and effort, investing in energy efficient technology can be costly, switching off appliances may be more effortful than leaving them on standby, and using particular appliances only when sufficient renewable energy sources are available limits freedom of choice. Yet, many people do engage in such behaviors, even though they are somewhat costly or effortful. What motivates people to engage in costly or effortful sustainable energy behavior?

People not only consider individual consequences of behavior, but also collective consequences. Sustainable energy behaviors benefit the environment as they result in a reduction of CO_2 emissions (Steg et al., 2014b). People are motivated to see themselves as morally right, which may encourage sustainable energy behaviors, as this indicates that one is doing the right thing (Bolderdijk et al., 2013b). This implies that sustainable energy behavior not only results from individual considerations, but also from moral considerations. Indeed, several studies revealed that moral considerations affect sustainable energy behavior, such as the purchase of energy-saving light bulbs and meat consumption (Harland et al., 2007), electricity saving at work (Zhang et al., 2013), energy saving behaviors at home (Van der Werff and Steg, 2015), and the acceptability of energy policies (Steg et al., 2005; Steg and De Groot, 2010). Interestingly, engaging in sustainable energy behavior may make people feel good because they derive pleasure and satisfaction from doing the right thing (Bolderdijk et al., 2013b; Venhoeven et al., 2013; Taufik et al., 2014). People may even physically feel warmer by engaging in sustainable energy behavior; this phenomenon is known as a warm-glow effect (Taufik et al., 2014).

Engaging in sustainable energy behavior is likely to strengthen the environmental self-identity, that is, the extent to which a person sees himself or herself as a pro-environmental person (Cornelissen et al., 2008; Van der Werff et al., 2013, 2014a). Environmental self-identity is particularly strengthened when people engaged in pro-environmental behaviors that are somewhat costly or uncommon, probably because such behaviors are more likely to signal how pro-environmental a person is (Van der Werff et al., 2014a). As indicated above, a strong environmental self-identity is likely to encourage positive spillover effects. This implies that people may engage in a wide range of sustainable energy behavior when they realize they engaged in sustainable energy behaviors that are somewhat (but not too) costly or effortful (Van der Werff et al., 2014a).

An important question is to what extent people consider and weigh individual and collective considerations of sustainable energy behavior, and which factors enhance the likelihood that they will consider individual and collective consequences in the choices they make. Values appear to be an important factor in this respect. Values reflect life goals or ideals that define what is important to people and what consequences they strive for in their lives in general (Rokeach, 1973; Schwartz, 1992). Values are general motivational factors that can affect a wide range of evaluations, beliefs, and actions (Steg et al., 2014b). Four types of values have been found to be relevant for people's evaluations and behavior related to sustainable energy use: hedonic values that make people focus on pleasure and comfort, egoistic values that make people focus on safeguarding and promoting one's personal resources (i.e., money, status), altruistic values that make people focus on the well-being of other people and society, and biospheric values that make people focus on consequences for nature and the environment (De Groot and Steg, 2008; Steg and De Groot, 2012; Steg et al., 2014b).

Values affect how important people find different consequences of sustainable energy behaviors, and how they evaluate these consequences. More specially, people focus particularly on the characteristics of sustainable energy behaviors that have positive or negative implications for their important values (Steg et al., 2014b). In addition, people are more aware of environmental problems caused by their behavior when they more strongly endorse biospheric values, or less strongly endorse egoistic values (Stern et al., 1995; Nordlund and Garvill, 2002; Schultz et al., 2005; Steg et al., 2005). This in turn influences their beliefs and choices. As explained before, many sustainable energy behaviors have positive collective consequences, and negative individual consequences. In line with this, research revealed that in general, people have more favorable evaluations of and are more likely to engage in sustainable energy behaviors if they have strong biospheric and, to a lesser extent, altruistic values, while they are less likely do so if they have strong egoistic and/or hedonic values (see Steg and De Groot, 2012, for a review). Yet, in some cases strong altruistic values can inhibit sustainable energy behavior, for example, when such behavior is believed to have negative consequences for the wellbeing of others (De Groot and Steg, 2008). Strong biospheric values also affect sustainable energy behavior via one's environmental self-identity (Whitmarsh and O'Neill, 2010; Gatersleben et al., 2012; Van der Werff et al., 2013, 2014b), in turn increasing the likelihood of positive spillover effects, as explained earlier.

Contextual Factors

In general, people care about the environment, and endorse biospheric values. Yet, many people do not consistently engage in sustainable energy behavior. How can we explain this value-behavior gap? Besides a lack of knowledge on the environmental implications of one's behavior, and lack of motivation to do so, sustainable energy behavior can be inhibited by various contextual factors. These contextual factors define the costs and benefits of different energy behaviors thereby influencing individual motivations (Ölander and Thøgersen, 1995; Stern, 1999; Thøgersen, 2005; Lindenberg and Steg, 2007; Steg and Vlek, 2009). For example, cycling rather than driving will be more effortful when people have to travel long distances, while subsidy schemes can make investments in solar panels or investments in energy efficient technology more affordable, which may result in more favorable evaluations of these technologies. Hence, in some cases, contextual factors facilitate sustainable energy behavior, and support individuals' biospheric values and moral considerations. For example, the provision of recycling schemes and recycling facilities promote recycling (Guagnano et al., 1995). Interestingly, this study also showed that moral considerations were less predictive of behavior when contextual factors strongly supported the behavior (i.e., when recycling bins were provided), suggesting that when behavioral costs are very low, everyone engages in the behavior, irrespective of the strength of their biospheric values and moral considerations. In other cases, contextual factors can inhibit people to act upon their biospheric values and moral considerations (Harland et al., 1999; Diekmann and Preisendörfer, 2003; Abrahamse and Steg, 2009, 2011; Steg et al., 2011). Contextual factors even may make some behaviors simply impossible (e.g., Guagnano et al., 1995; Corraliza and Berenguer, 2000).

Besides defining the costs and benefits of sustainable energy behaviors, contextual factors can serve as cues that activate specific values in a particular situation, making it more likely that these values steer decision making in that situation (Steg et al., 2014a; Steg, 2015). For example, bikini models or chocolate can activate hedonic values; status symbols or signs of money can activate egoistic values; while Bibles, churches, statues of Justitia and environmental symbols can activate altruistic and biospheric values (Verplanken and Holland, 2002; Lindenberg and Steg, 2007; Lindenberg, 2012; Perlaviciute, 2014). Also, high behavioral costs are likely to activate values related to these costs, notably hedonic and egoistic values, which makes it less likely that people act upon their biospheric values (Steg et al., 2014a; Steg, 2015). Furthermore, signs of immoral or norm violating behavior by others can activate hedonic and egoistic values, making altruistic and biospheric values less influential in the particular choice situation. The opposite is true for cues that clearly signal that others respect norms and acted morally right (Steg et al., 2014a; Steg, 2015).

Interventions to Promote a Sustainable Energy Transition

Various studies have examined which interventions are effective to promote a sustainable energy transition. From the 1970s, these studies focused on reducing energy demand by encouraging household energy conservation behavior and investments in energy efficiency, as to prevent the exhaustion of fossil energy sources. From the 1990s, studies focused on reducing CO_2 emissions. Whereas initially many studies focused on encouraging energy saving behavior, recently more studies focused on promoting the adoption of energy saving technologies and ways to motivate households to balance their energy demand to the available supply of (renewable) energy. Below, we review the literature on interventions to encourage sustainable energy behavior. We first discuss structural strategies that aim to enhance people's ability and motivation to engage in sustainable energy actions, by making such actions relatively more attractive via incentives. Second, we discuss psychological strategies that aim to increase people's ability and motivation to engage in energy saving actions without actually changing the costs and benefits of these actions.

Structural Strategies

As indicated earlier, some sustainable energy behaviors involve some degree of effort, discomfort or are financially costly. For example, putting on a sweater instead of turning on the heater or taking shorter showers can be perceived as less comfortable, and investing in home insulation involves initial financial investments. This implies that sustainable energy behaviors are oftentimes not pleasurable or rewarding (at least in the short term) as such. It is often assumed that people are not motivated to act sustainably unless some personal benefits are involved (Penn, 2003). This implies that external incentives would be needed to motivate people to engage in sustainable energy behavior, such as subsidies, or special arrangements such as free parking spaces for electric cars (cf. Bolderdijk and Steg, 2015). Alternatively, external incentives could make unsustainable energy use more costly or less pleasurable, for example, by introducing taxes or laws and regulations; a key issue here is that such strategies often lack public support. Incentives that are aimed at changing contextual factors that define the costs and benefits of sustainable energy choices are sometimes necessary to facilitate sustainable energy choices (Geller, 2002; Steg and Vlek, 2009; Bolderdijk et al., 2012). For example, only few people would be willing to purchase an energy efficient appliance that is more than twice as expensive as other options. Yet, perceptions of costs and benefits of behavior are not always accurate. In such cases, it may be sufficient to change the perceptions of costs and benefits of options via information strategies that aim to correct such misperceptions (Steg and Vlek, 2009; Abrahamse and Matthies, 2012).

Strategies that mainly deliver and stress incentives may be less effective than sometimes assumed, and can sometimes even be counter-effective (e.g., Asenio and Delmas, 2015; see for a review, Bolderdijk and Steg, 2015). The effects of incentives strongly depend on non-financial factors, such as ease of participating or program marketing (Carrico et al., 2011). Incentives provide a fickle basis for consistent sustainable energy choices when employed in isolation. They make people focus on immediate personal costs and benefits of behavior (Steg et al., 2014a; Steg, 2015). Consequently, people will particularly engage in sustainable energy behaviors when such behavior is extrinsically rewarding (De Groot and Steg, 2009). Indeed, it was found that positive effects of financial incentives to promote eco-driving disappeared as soon as the incentives were removed (Bolderdijk et al., 2011). In addition, external incentives can inhibit positive spillover effects when subsequent actions have no clear external reward, which is not uncommon in the energy domain (Thøgersen, 2013). For example, people who focused on economic rather than environmental reasons for one pro-environmental act, in this case car-sharing, appeared to be less inclined to engage in another sustainable behavior on a following occasion, in this case recycling (Evans et al., 2013). Similarly, if people engage in sustainable energy behavior due to rules or regulations, rather than due to autonomous choice, the behavior may have a weaker signaling value for prestige or identity effects, and therefore be less likely to strengthen environmental self-identity and to promote positive spillover. This implies that many different incentives need to be implemented to encourage wide-scale behavior changes needed to realize a successful sustainable energy transition, each increasing the relative attractiveness of the specific behavior targeted. This is overall not efficient and cost-effective. In addition, external incentives will only result in behavior changes when such changes are perceived to be worth the effort (Bolderdijk and Steg, 2015). For example, appeals emphasizing the financial benefits of tire pressure checks, which are modest, were not effective at all (Bolderdijk et al., 2013b). Many single sustainable energy behaviors yield small benefits and are therefore perceived as not worth the effort (Dogan et al., 2014). For example, unplugging a single coffee machine or microwave would save less than 6 Euros a year. Hence, although targeting extrinsic motivations by introducing incentives may be needed to promote some sustainable energy behaviors, incentives are not likely to encourage people to engage in the many sustainable energy behaviors needed in a truly sustainable energy transition.

Psychological Strategies

For this reason, it is also important to employ strategies that target or enhance motivation to engage in sustainable energy behavior. Particularly strategies that target and strengthen individuals' intrinsic motivation to engage in sustainable energy behavior may be promising in this respect, as such strategies are more likely to result in durable behavior changes.

To start with, information can be provided as to change consumers' beliefs about and to increase their awareness of environmental and social problems caused by their behavior, which may enable and motivate them to help reduce these problems by changing their behavior. Research suggests that providing general information about energy problems and energy conservation indeed often leads to an increase in knowledge and awareness (Staats et al., 1996; Bradley et al., 1999), but this increase in knowledge does not necessarily translate into behavior changes (Geller, 1981; Staats et al., 1996; Gardner and Stern, 2002; Abrahamse et al., 2005). Information is more likely to encourage sustainable behavior when it resonates with people's central values. For example, whereas an environmental campaign increased knowledge among all exposed to the campaign, it only affected sustainable behavioural intentions and policy preferences for those who strongly endorsed biospheric values (Bolderdijk et al., 2013a). More generally, information strategies have been more successful when they are tailored to the needs, wants and perceived barriers of the target population (Abrahamse et al., 2005, 2007; Thøgersen, 2005). Besides, the effects of information provision depends on the sources of the information and how people evaluate those sources (Clayton et al., in press); information is more likely to change beliefs and behavior if people evaluate the source favorably and trust the source.

People can also learn about which personal actions are effective to promote a sustainable energy transition by providing them with feedback about their energy use or energy savings that they have realized. Feedback appears to be an effective strategy for reducing household energy use (e.g., Seligman and Darley, 1977; see Abrahamse et al., 2005, for a review), although some exceptions exist (e.g., Katzev et al., 1980–1981; see Fischer, 2008). Feedback is more effective when it is given immediately after the behavior occurs, as this enhances people's understanding of the relationship between the feedback and their behavior (Geller, 2002). Also, research suggests that the more frequently the feedback is given, the more effective it is. Positive effects have for instance been found for continuous feedback (e.g., McClelland and Cook, 1979–1980). Smart meters offer possibilities for providing immediate and frequent feedback on household energy use via different means such as websites, mobile phones, and home displays (Sintov and Schultz, 2015). Smart meters, however, typically give feedback on overall energy use, which might still tell little to people about how they can reduce their energy use. In this respect, feedback on a more detailed level, for example, on an appliance level, may be more effective (Fischer, 2008). When consumers lack the motivation or resources to consciously process information or feedback on their energy behaviors, ambient persuasive technologies can be offered that promote behavior change without the need for user's conscious attention and hence with little cognitive effort (Midden and Ham, 2012). For example processing interactive lighting feedback, such as a light that turns green, is less cognitively demanding than processing factual feedback, such as statistics on your energy use, and may facilitate and motivate people to engage in sustainable energy behavior even in cognitively demanding situations.

Various social influence strategies can be employed to encourage sustainable energy behaviors (see Abrahamse and Steg, 2013, for a review). Social influence approaches that make use of face-to-face interaction seem most effective in this respect, such as block leader approaches, and behavior modeling. In fact, block leader approaches, in which case local volunteers help inform other people in their neighborhood about a certain issue, seem to be one of the most effective social influence strategies. Block leader approaches are particularly effective when the relevant social network has more ties (Weenig and Midden, 1991). Behavior modeling entails the use of confederates or "models" who demonstrate a recommended behavior, and appears to be an effective strategy to encourage sustainable behavior too (Winett et al., 1985; Sussman and Gifford, 2013).

Other effective social influence strategies are commitments, in which case people make a promise to engage in sustainable energy behavior, and implementation intentions, in which case people not only promise to engage in sustainable energy behavior, but also indicate how and when they will do so. Importantly, both strategies appear to have long-term effects on sustainable behavior (see Abrahamse et al., 2005; Abrahamse and Steg, 2013; Lokhorst et al., 2013, for reviews). Commitments are more effective when made in public rather than private (Abrahamse et al., 2005). Although little is known about the processes through which both strategies promote behavior changes, one plausible explanation is that they strengthen personal norms. More specifically, once people committed themselves to engage in sustainable energy behavior, they are motivated to act in line with their promise, as they want to (appear to) be consistent (Abrahamse and Steg, 2013). Another strategy that makes use of individuals' desire to be consistent is evoking cognitive dissonance between people's reported attitudes and behavior. Such a hypocrisy strategy appears to be effective. For example, people who first reported a favorable attitude toward energy conservation, and later were made aware of their relatively high energy usage, significantly reduced their energy use (Kantola et al., 1984; see also Focella and Stone, 2013).

Social influence strategies that generally happen in a fairly anonymous way, such as descriptive norm information, social comparison feedback, and group feedback, can also encourage sustainable behavior, but seem to be less powerful than strategies that rely on face-to-face interactions (Abrahamse and Steg, 2013). The provision of descriptive norm information, that is, providing information on the behavior of others, and social comparison feedback in which case people receive feedback about one's own performance compared with the performance of others, and providing feedback on the performance of a group can be effective in promoting sustainable energy use, although the effect size is not very strong (see Abrahamse and Steg, 2013, for a meta-analysis). Social norm information and social comparison feedback is not very effective when most (significant) others do not act sustainably. In fact, if individuals learn that most others do not engage in sustainable energy behaviors, providing feedback on the behavior of others may even be counter effective, as people are likely to follow this norm (Brandon and Lewis, 1999; Schultz et al., 2007). Another important issue to consider is that information on the behavior of others should be credible. For example, it would be unwise to communicate that most others engage in sustainable consumption while it is obvious that this is not actually the case (cf. Terwel et al., 2009).

Besides informing people about the sustainable energy behavior of others, they can also be reminded of sustainable energy behaviors they themselves already engaged in. As explained earlier, such strategies are likely to strengthen one's environmental self-identity, particularly when one's previous behaviors clearly signal that one acted pro-environmentally, thereby promoting subsequent sustainable energy behaviors (Van der Werff et al., 2014a). As discussed above, the latter is more likely to be the case when people are reminded of a range of sustainable energy actions they engaged in, or when they are reminded of behaviors that were somewhat costly or uncommon. This implies an interesting paradox. On the one hand, it may be beneficial to stress that many others act sustainably, as people are likely to act in line with such descriptive norms. Yet, on the other hand, it seems that stressing that only few people acted sustainably can also encourage sustainable energy choices, via a different process, as engaging in such behavior can strengthen one's environmental identity. An important question for future research is to understand the conditions under which each of these strategies would be most effective. For example, it may depend on whether one is a potential early adopter of sustainable energy behaviors or not.

Acceptability of Energy Policies and Changes in Energy Systems

Energy policies and energy system changes will mostly not be implemented when they lack public support. Hence, it is important to understand what factors influence public acceptability of energy policies and energy system changes. Moral considerations affect policy support: acceptability of energy policies is higher when people are highly aware of energy problems and feel morally obliged to reduce these problems (Steg et al., 2005). Furthermore, energy policies and energy system changes are evaluated as more acceptable when they do not seriously threaten people's freedom of choice (Poortinga et al., 2003; Steg et al., 2006; Schuitema et al., 2010; Leijten et al., 2014). More generally, people evaluate energy policies and changes in energy systems as more acceptable when these policies and changes are expected to have more positive and less negative individual and/or collective consequences (Dietz et al., 2007; Shwom et al., 2010; see Schuitema and Jakobsson Bergstad, 2012, for a review). Below, we discuss two factors that affect how people perceive and evaluate various consequences of energy policies and energy system changes, namely values and trust in involved parties. In addition, public acceptability depends on how and by whom energy policies and energy systems are developed and implemented. We describe two factors that play a crucial role in this respect, namely the distribution of costs and benefits, and public engagement and participation.

Values and Acceptability

People are more likely to accept energy policies and changes in energy systems when these policies and changes align with and support their important values. For example, stronger egoistic values were associated with more positive evaluations of nuclear energy, probably because nuclear energy is believed to have mainly positive implications for one's egoistic vales, such as affordable and secure energy supply. In contrast, stronger egoistic values were related to less positive evaluations of renewable energy sources, which may have negative consequences for one's egoistic values, such as being expensive and intermittent. Similarly, stronger biospheric values were related to more positive evaluations of renewable energy sources, which are generally seen as having positive implications for one's biospheric values, such as a reduction in CO_2 emissions. Biospheric values were related to less positive evaluations of nuclear energy, which is believed to have negative implications for one's biospheric values, such as contamination in case of nuclear accidents (Corner et al., 2011; De Groot et al., 2013; Perlaviciute and Steg, 2015). Interestingly, people's value-based judgements of energy sources may affect their evaluations of various consequences of these energy sources, including consequences that should not be particularly important to them given their values. For example, people with strong egoistic values were most likely to ascribe positive environmental consequences to nuclear energy, such as a reduction of CO_2 emissions. People with strong biospheric values evaluated personal consequences of renewable energy sources more positively, such as costs and the security of energy supply, even though these consequences are probably not very important to them given their specific values (Bidwell, 2013; De Groot et al., 2013; Perlaviciute and Steg, 2015). This suggests that people base their evaluations of energy policies and changes in energy systems primarily on aspects that are most relevant for their important values, which will guide their acceptability ratings. These value-based acceptability judgements may further affect the evaluation of other characteristics of these policies and energy system changes, which may be less important to people based on their values. In other words, people are likely to evaluate energy policies and changes in energy systems in an overly positive or negative way that is in line with their value-based judgements.

Interventions aimed at strengthening public support for sustainable energy policies and energy system changes will be more effective if they target values that underlie people's evaluations and acceptability ratings (cf. Bolderdijk et al., 2013a). Focusing merely on how people evaluate various consequences of these policies and energy system changes may be misleading, given that (some of) these evaluations can be colored by people's values-based judgements and not reflect the actual concern people have, as we explained above. For example, people may evaluate renewable energy sources or energy efficient technology negatively, primarily because they expect negative consequences for their egoistic values related to increased costs and/or intermittency. Yet, as a consequence, they may also evaluate the environmental consequences of renewable energy sources or energy efficient technology negatively, in line with their value-based judgements. In this case, targeting the environmental consequences in intervention strategies will probably not change their acceptability ratings, as the acceptability judgements were hardly based on the evaluation of the environmental consequences in the first place. In this case, introducing subsidies for adopting renewable energy or improving the functionality of energy systems could be more motivating for them; such strategies could at the same time enhance intrinsic motivation to support durable changes in behavior, as explained above. Interestingly, while privacy concerns with regard to energy use monitoring technology such as smart metering may hinder acceptability of such technology, a study found that privacy concerns may be underpinned by the costs and benefits that people expect from such technology for them personally (Bolderdijk et al., 2013c). More specifically, privacy concerns were most prominent when people anticipated negative individual consequences (e.g., paying more for energy use) from implementing the monitoring technology. Communicating the individual benefits of such technology (e.g., the possibility to save money) alleviated privacy concerns. A thorough understanding of which values actually underlie people's evaluations and acceptability ratings is therefore crucial for developing effective intervention and communication strategies.

Trust in Involved Parties and Acceptability

Sustainable energy transitions entail multiple aspects, such as complex energy technology, that go far beyond the knowledge and expertise of consumers. People therefore need to rely on other parties, such as developers, governments, and scientists, to develop their views of different aspects related to sustainable energy transitions. The extent to which people trust these parties will influence acceptability of energy policies and changes in energy system (Whitfield et al., 2009; Huijts et al., 2012; Perlaviciute and Steg, 2014). Trust in involved parties will especially affect evaluations and perceptions when people have little knowledge about the proposed energy policies or energy system changes (cf. Siegrist and Cvetkovich, 2000). Trust can influence the perceived costs and benefits of sustainable energy transitions. For example, the more people trusted the parties involved in managing hydrogen systems, the more benefits and the less risks they ascribed to hydrogen as an energy carrier in cars and busses (Montijn-Dorgelo and Midden, 2008). The effects of trust on perceived risks and benefits were mediated by general attitudes toward hydrogen, in this study conceptualized as general affective evaluations (Montijn-Dorgelo and Midden, 2008).

People base their trust judgements on the perceived competence and the perceived integrity of the involved parties (Earle and Siegrist, 2006; Terwel et al., 2009). More specifically, it is not only important whether people think that the parties involved have sufficient knowledge and expertise, but also how these parties have performed in the past, whether people perceive them as open, honest, and taking their interests into account, and whether people think these parties endorse values similar to their own values (Earle and Siegrist, 2006). In general, people tend to trust universities and NGO's more than companies and governments, although local governments are typically trusted more than national governments. This is likely to be driven by the perceived values and motivations of these actors. Specifically, people may assume that companies primarily value profit making, which, especially in the energy sector, can be seen as conflicting with public interests. In a study on sustainable energy transitions in the UK, people expressed much support for shifting toward renewable energy sources, but at the same time they expressed their concern whether the energy companies are capable of realizing sustainable energy transitions in a way that aligns with societal and environmental values (Butler et al., 2013). Lack of trust in energy companies can also elicit privacy concerns related to, for example, smart metering technology, which can weaken public support for the proposed sustainability measures (Butler et al., 2013). Interestingly, a study on acceptability of CO_2 storage found that when people perceived themselves and professional parties as sharing similar goals and values, they expected these parties to not only have good intentions but also sufficient skills and competencies to pursue these intentions (Huijts et al., 2007). This again shows that values play an important role in public acceptability of energy policies and changes in energy systems, and that values can affect trust in involved parties.

Distribution of Costs and Benefits

Acceptability of energy policies and energy systems changes not only depends on their benefits, costs and risks, but also on how these benefits, costs and risks are distributed among groups involved. Sustainable energy transitions will be seen as unfair if certain groups in society face most of the costs, while other groups in society mainly enjoy the benefits, which may reduce their acceptability (Schuitema and Jakobsson Bergstad, 2012). For example, communities hosting renewable energy technologies such as wind farms may experience noise and visual hinder, while the possible benefits such as reduced CO_2 emissions, affordable energy, and energy independence are shared on a national or even global scale. As a consequence, people may oppose these technologies.

Fair distribution of costs and benefits can be pursued in multiple ways, which are not mutually exclusive. First, risks and costs of energy policies can be reduced as much as possible in order to secure public acceptability. For example, technical solutions can be sought to reduce the noise caused by wind turbines, and costs of renewable energy sources can be reduced via subsidies. A second (parallel) strategy to pursue a fair distribution of costs, risks and benefits is providing additional benefits to those exposed to most costs and risks. For example, individuals can be financially compensated, or developers of renewable energy projects could establish local funds that can be used to reduce energy bills for local people, to stimulate local economy, or to create or expand local facilities (e.g., sports facilities; Walker et al., 2014). It has been proposed that collective benefits (e.g., investing in local facilities) are less likely to be seen as "bribes" by citizens than individual financial compensations (e.g., one-time payments to residents; Ter Mors et al., 2012). However, this proposition has not been empirically tested. Interestingly, the amount of compensation may be less important for acceptability judgements than who will benefit from the compensation. For example, people prefer royalties from a wind energy project to be allocated to local funds rather than to state funds (Krueger et al., 2011). This is probably because it is seen as more fair when local communities benefit from hosting energy infrastructure than when benefits are allocated to state funds (cf. Schuitema and Steg, 2008). Yet, financial compensation to local funds will not enhance acceptability and may even backfire when such compensations are perceived as attempts to "buy local support" (Walker et al., 2014; cf. Ter Mors et al., 2012).

Public Involvement

People may be more likely to accept energy policies and changes in energy systems if they believe that the decision-making process is fair, and if they feel they are sufficiently involved in decision-making and that their interests are considered (Huijts et al., 2012; Perlaviciute and Steg, 2014). Public involvement can take place at different levels, which will affect acceptability differently (Devine-Wright, 2011). Information provision is a necessary pre-condition for public involvement: decision-making processes need to be transparent and people should be fully informed from the beginning, rather than only afterwards when all decisions are made. Yet, information provision alone is a passive form of public involvement and is often not sufficient to secure public support for energy policies and energy system changes. Higher levels of public involvement include active public engagement in decision-making (Devine-Wright, 2011). Several case studies on renewable energy projects have concluded that technocratic top-down decision making processes inhibit public acceptability, while collaborative approaches taking community concerns into account enhance acceptability (Wolsink, 2007, 2010; Wolsink and Breukers, 2010; Walker and Devine-Wright, 2008). Public engagement means not only that people will have an opportunity to express their opinion, but also that their opinion is seriously considered in decision-making and can have an actual impact on decisions on energy policies and changes in energy systems (see Dietz and Stern (2008), for a review of dimensions and assessment criteria of participatory processes). People consider decisions more acceptable if they have been actively involved in the decision-making process (also conceptualized as legitimacy; Dietz and Stern (2008), Schuitema and Jakobsson Bergstad, 2012). Sometimes, however, people are given an opportunity to express their opinion, while their opinion is eventually not taken into account and cannot change energy policies. Such "fake" engagement can have even more negative effects on public support than no engagement at all, by diminishing trust in involved parties, as discussed above.

Discussion

In this paper, we discussed factors influencing sustainable energy behavior by individuals and households. We proposed a general framework to study ways to understand and encourage sustainable energy behaviors needed to promote a sustainable energy transition, comprising four key issues. First, we argued that a sustainable energy transition involves changes in a wide range of energy behaviors, including the adoption of sustainable energy resources and energy-efficient technology, investments in energy efficiency measures in buildings, and changes in energy use behavior. Besides, not only direct energy use should be considered, but also indirect energy use, that it, the energy used to produce, transport and dispose of products. Second, we proposed that it is important to examine main factors underlying different types of sustainable energy behaviors. We discussed three main factors influencing such behavior that are closely intertwined: knowledge, motivations, and contextual factors. Third, it is important to test the effects of interventions aimed to promote sustainable energy behavior by changing important antecedents of these behaviors. In this respect, it is not only important to study structural strategies that affect the actual costs and benefits of behavior, but also psychological strategies that affect how people perceive and evaluate different pros and cons of behavioral options. Fourth, as policies and energy system changes will probably not be implemented when they are not supported by the public, it is important to understand which factors affect the acceptability of energy policies and energy system changes. We discussed that acceptability judgements depend on the perceived benefits, costs and risks of energy policies and energy system changes, and argued that these depend on people's values and trust in the parties involved. Besides, perceived fairness plays a role, which depends on the distribution of benefits, costs and risks, and the level of public involvement in the decision making process.

Our review reveals that many studies followed a narrow approach, by studying specific antecedents of single energy behaviors or effects and acceptability of specific policies or energy system changes. We emphasize the need of an integrated approach in studying the human dimensions of a sustainable energy transition that increases our understanding of which general factors affect a wide range of energy behaviors as well as the acceptability of energy policies and energy system changes. Below, we propose a research agenda for studying the human dimensions of a sustainable energy transition.

Research Agenda for Studying the Human Dimension of a Sustainable Energy Transition

Future energy systems will likely more strongly rely on renewable energy sources, such as solar or wind energy. To realize a sustainable energy transition, we need to study a range of sustainable energy behaviors in an integrated way. First, we need to understand to what extent and under which conditions individuals and households are willing to accept and adopt different renewable energy sources. Second, to enhance the efficiency of sustainable energy systems and to meet energy demands of individuals and households across the world, total energy demand needs to be reduced. For this purpose, we need to systematically study factors that increase the efficiency of energy systems. More particularly, we need to understand which factors affect investments in energy efficiency, such as refurbishment of houses and adoption of energy-efficient appliances. Also, we need to understand which factors affect daily energy use, such as thermostat settings or showering time. Third, given that the production of energy from renewable resources may strongly vary with weather conditions and that renewables are not always readily available, we need to study preferences for and acceptability of different ways to balance demand and supply of energy produced from renewable resources. Are people willing to shift energy use in time as to balance energy demand and supply, either autonomously or via automated technologies? Or do they prefer storage facilities such as "power-to-gas," batteries and electric cars? Which factors influence the preferences for these different solutions? Fourth, besides reducing direct energy use, it is also important to consider indirect energy use which comprises about half of total household energy use. More research is needed on the extent to which people are aware of indirect energy use, and whether and under which conditions they consider indirect energy use in the decisions they make. Ideally, studies include measures of actual energy behavior and actual energy use, rather than only behavioral intentions or self-reported behavior (cf. Gatersleben et al., 2002). Various technologies have become available that enable objective measures of behavior and energy use, such as smart meters and smart plug systems.

When studying these different types of sustainable energy behaviors in an integrated way, it is important to understand factors increasing the likelihood of possible negative versus positive spillover effects. More specifically, it is important to examine the conditions under which engagement in sustainable energy behaviors gives people the feeling that they are licensed to refrain from other sustainable energy behaviors, thereby causing negative spillover. Moreover, it is important to understand how to prevent that sustainable energy behavior leads to negative spillover or "rebound" effects. Similarly, future research can examine under which conditions positive spillover effects are more likely, increasing the likelihood that people are willing to engage in many different sustainable energy behaviors over and again, which is needed to realize a truly sustainable energy transition. As discussed earlier, positive spillover effects seem more likely when people ascribe the initial behavior to themselves, thereby strengthening their environmental self-identity. Future research is needed to systematically test under which conditions the environmental self-identity will be particularly strengthened after engaging in sustainable energy behaviour, and which factors motivate people to act in line with this identity over and again (Whitmarsh and O'Neill, 2010; Truelove et al., 2014). More generally, future research can study the processes underlying positive and negative spillover effects in more depth. Self-perception theory, goal theory and cognitive dissonance theory provide possible theoretical explanations for the processes through which spillover effects occur (e.g., Thøgersen and Crompton, 2009; Thøgersen and Noblet, 2012). The question remains under which circumstances which theoretical explanation is most plausible.

Spillover effects are typically studied in lab studies focussing on one-off environmental behaviors (Truelove et al., 2014). A sustainable energy transition requires that people engage in many different sustainable energy behaviors over and again, for example when they choose whether to take a shower, what products or appliances to buy, which appliances to use in their homes, and which energy carriers to use. Future research is needed to study the scope of spillover effects, that is, which type of behaviors are particularly influenced, how many behaviors are influenced, and the pattern of spillover effects over a longer period of time. To be able to establish causality, longitudinal experimental designs need to be employed. From a broader sustainability perspective, not only spillover effects within the energy domain should be considered, but also spillover across various types of environmental behavior such as energy use, water use and waste handling.

In order to better understand why people would or would not engage in a wide range of sustainable energy behaviors, it is important to study general antecedents of such behaviors, such as values. Our review suggests that particularly strong biospheric values can create a stable and reliable basis for many sustainable energy behaviors, even if these behaviors have some personal costs. Yet, people do not always act upon their biospheric values, for example because they are not able to do so due to contextual restrictions or because cues in a given situation activate other conflicting values. It is important to study under which conditions people are more or less likely to pursue their biospheric values and how biospheric values can be activated by situational cues, so that they are more likely to steer decisions in a particular situation. Next, we know yet very little about the extent to which people's value priorities change. Although values are considered to be relatively stable across time, changes in values have been documented due to, for example, significant life events (Steg et al., 2014a). Future research could shed more light on factors that make people reconsider the importance of their values, in particular the importance of biospheric values, for example through intensive environmental education programs.

Knowledge about energy problems and ways to reduce these problems can be an important precondition to promote a sustainable energy transition. In this respect, it is important to study factors that determine whether or not knowledge and information lead to more sustainable energy behavior. One important question is which types of knowledge are particularly important to change people's concerns, beliefs, and perceived efficacy to engage in sustainable energy behavior, and their actual behavior. Next, given new developments in the sustainability domain, such as smart metering systems that can offer detailed feedback on one's energy use and savings, it is important to study which type of feedback (e.g., financial, environmental, or social comparison feedback) is most effective to encourage sustainable energy behavior, and under which conditions these changes are most likely.

Sustainable energy transitions will bring changes in energy systems, and involve the implementation of different energy policies. The extent to which these policies and system changes can be implemented will depend on public acceptability. This review suggests that values and trust affect how people perceive different benefits, costs and risks of energy systems and energy policies. Future research can examine how and under which conditions values and trust particularly affect perceived consequences and acceptability of energy system changes and energy policies. Also, more systematic research is needed on factors influencing perceptions of the distribution of costs and benefits of policies and energy system changes, and on ways to enhance distributive fairness by reducing the (local) costs and risks, and enhancing the benefits of energy transitions. In this respect, it is particularly important to systematically study how different types of benefits or compensations (e.g., financial versus in-kind) and differences in how these benefits are allocated (e.g., individual versus local versus national) influence public acceptability.

Active public involvement in decision-making can foster sustainable energy transitions that are acceptable to the public. The current conceptualisation of public involvement entails many components that are potentially important for public acceptability, including transparency in information provision and decision-making, possibilities to voice public opinion, and integrating public opinion in decision-making. It is important to systematically study the effects of these different components of public involvement on public acceptability, and to study how public involvement can best be organized to enhance public support for proposed solutions by carefully taking into account the interests of different stakeholders (see also Dietz and Stern, 2008, for research priorities in this area).

A sustainable energy transition to combat anthropogenic climate change involves fundamental and wide-scale changes in human perceptions, preferences and behavior. Achieving these changes in perceptions, preferences and behavior calls for a prominent role of social scientists in understanding how to motivate and enable people to actively contribute to a sustainable energy transition. We proposed an integrated approach to address this challenge that increases our understanding of how to motivate and empower individuals and households to engage in a wide range of sustainable energy behaviors that are needed to encourage a sustainable energy transition.

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Affective influences on energy-related decisions and behaviors

Tobias Brosch[1,2]*, Martin K. Patel[3,4] and David Sander[1,2]

[1] Department of Psychology, University of Geneva, Geneva, Switzerland
[2] Swiss Center of Affective Sciences, University of Geneva, Geneva, Switzerland
[3] Energy Group, Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland
[4] Energy Group, Forel Institute, University of Geneva, Geneva, Switzerland

Edited by:
Joni Jupesta, United Nations University, Japan

Reviewed by:
Antonio Scala, Consiglio Nazionale delle Ricerche, Italy
Masaru Yarime, University of Tokyo, Japan

***Correspondence:**
Tobias Brosch, Department of Psychology, University of Geneva, 40, Boulevard du Pont d'Arve, Geneva CH-1205, Switzerland
e-mail: tobias.brosch@unige.ch

A successful energy transition will depend not only on the development of new energy technologies, but also on changes in the patterns of individual energy-related decisions and behaviors resulting in substantial reductions in energy demand. Across scientific disciplines, most theoretical approaches that try to understand energy-related decisions and behaviors focus mainly on cognitive processes, such as computations of utility (typically economic), the impact of cognitive heuristics, or the role of individual beliefs. While these models already explain important aspects of human decisions and behavior in the energy domain, we argue that an additional consideration of the contributions of emotional processes may be very fruitful for a deeper understanding of the issue. In this contribution, we outline a theoretical perspective on energy-related decisions and behaviors that integrates emotions, elicited by a cognitive-affective appraisal of the relevance of a situation, into a response system driving adaptive decisions and behaviors. We empirically investigate the explanatory power of the model variables to predict intentions to reduce energy use demonstrating that the appraisal–emotion variables are able to account for additional variance that is not explained by two established models focused on cognitive processes (theory of planned behavior and value-belief-norm theory). Finally, we discuss how the appraisal–emotion approach may be fruitfully integrated with other existing approaches and outline some questions for future research.

Keywords: affect, behavior, energy, decision-making, emotion

INTRODUCTION

An increasing number of countries have implemented policies targeting the increased use of renewable energy sources, improved energy efficiency, and the abatement of greenhouse gas emissions. The success of this energy transition will depend not only on the development of new energy technologies, but also on major changes in the patterns of individual energy-related decisions and behaviors resulting in substantial reductions in energy demand. To an increasing extent, this is being acknowledged by science and stakeholders. The Stern Review on the Economics of Climate Change, for example, points out the removal of barriers to behavioral change as one of three essential elements of energy and climate policy (next to carbon pricing and technology policy; Stern, 2007). It is thus of crucial interest for society and policy makers to gain an understanding of the underlying factors and mechanisms that drive these decisions and behaviors.

Given the importance of the issue, several disciplines of the behavioral sciences have advanced theoretical frameworks that aim to identify target variables for potential interventions to reduce energy demand (see Wilson and Dowlatabadi, 2007 for a review). For example, classic microeconomic approaches focus on the "rational actor" model, which assumes that people make their decisions by comparing the utility of the different available options and by choosing the outcome with the highest utility, while having access to all the important information that is needed for a rational decision (Becker, 1976). In their decisions, people are assumed to act based on preferences that are known to them, invariant and consistent, and always aiming at the maximization of their utility. Utility is often expressed in monetary terms, and interventions that aim at changing energy-related decisions and behaviors are mainly focusing on changes in price structures (e.g., increasing energy prices), which result in an increased utility of reducing one's energy use (Tietenberg, 1990). More recently, approaches from the field of behavioral economics have gained popularity. They take into account empirical observations showing that individuals' decisions are not always based on rational deliberations, but are subject to a number of cognitive shortcuts and biases (Kahneman, 2003). For example, people tend to be overly influenced by cognitive anchors (e.g., the *status quo*; see Samuelson and Zeckhauser, 1988) or by the framing of the choice situation (e.g., whether it emphasizes potential losses or gains; see Tversky and Kahneman, 1981). These biases can be exploited when decision situations are designed in a certain manner in order to "nudge" people toward decisions and behaviors that reduce energy use (Thaler and Sunstein, 2008), e.g., by changing default settings on household appliances to less energy-intensive programs.

Whereas economic approaches mainly focus on aspects of the decision situation, especially the underlying incentive structure, psychological approaches emphasize the importance of internal factors on the side of the decider, such as belief structures, value systems, attitudes, or norms (Ajzen, 1991; Stern, 2000). Individual differences in, for example, beliefs about the causes or the importance of climate change or explicit attitudes toward energy conservation are considered important drivers of energy-related decisions. Interventions based on these approaches may include strategies that aim at changing people's beliefs or attitudes (Cialdini, 2009) in order to promote reductions in energy use, and may be tailored to specific groups of people (such as people with high environmental values, see, e.g., Sutterlin et al., 2011).

Across disciplines, most theoretical approaches that try to understand energy-related decisions and behaviors focus exclusively on cognitive processes. Computations of utility, the impact of cognitive heuristics, or the role of individual beliefs and social norms are considered the main drivers of relevant decisions. Only a few theories take into account the role of affective processes and emotions (see, e.g., Kals and Muller, 2012). If these processes are considered, they are often conceptualized as biases that interfere with rational thinking. For example, peoples' judgments about the risks and benefits of nuclear energy are explained by their initial affective responses and gut feelings (Finucane et al., 2000); intensive car use is explained by strong emotional attachment to the car (Marsh and Collett, 1986). Emotions are thus reduced to an irrational bias that leads to suboptimal decisions that are not in the best interest of the individual or the environment.

The view of emotions as an irrational force that opposes cognition and reasoned thought dominated in philosophy for many centuries (see, e.g., the writings by Plato or Descartes), and still today survives in many academic disciplines as well as in lay theories of emotion. However, over the last two decades, psychological and neuroscientific research on emotions has made great strides toward a revision of this conceptualization. Recent theories on the functioning of emotions consider emotion and cognition not as separate, opposing entities, but as strongly intertwined and complementary (Scherer, 2009; Brosch, 2013; Sander, 2013). Cognitive appraisal processes that automatically and continuously evaluate our environment to detect relevant information play a crucial role in the elicitation of emotions. Emotional responses carry important information about the value of objects or events in our environment, and help us focus on the most important aspects of the surrounding environment by adaptively modulating our cognitive systems (Brosch et al., 2013). Affective processes and emotions thus should not be considered as irrational forces that are counterproductive to our decision-making, but to the contrary as processes yielding important information that, together with cognitive considerations, can help us make very "rational" (i.e., adaptive and useful) decisions. Given the fundamental interest of society to understand energy-related decisions and behaviors, it may be fruitful and important to take into account affective and emotional processes, as they may contribute to a better understanding of the underlying mechanisms, improved predictions of the resulting choices and behaviors, as well as potential leverage for more effective interventions.

In this contribution, we outline a theoretical perspective on energy-related decisions and behaviors based on these recent theoretical developments[1]. In this perspective, emotional responses are integrated into a response system that drives adaptive decisions and behaviors based on a cognitive-affective evaluation. We begin by summarizing and discussing current developments in emotion psychology and neuroscience that describe how the perspective regarding the functionality (or "rationality") of emotion has changed over the last few decades ("affective turn"). We then describe two of the most influential theoretical models that have previously been used to explain energy-related decision-making and behavior, the theory of planned behavior (TPB, Ajzen, 1991) and the value-belief-norm theory (VBN, Stern, 2000). While these models already explain important aspects of human decisions and behavior in the energy domain, we argue that an additional consideration of the contributions of emotional processes may be very fruitful for a deeper understanding of the topic. To this end, we outline a perspective describing how appraisal processes and emotions may inform decisions and behaviors in the energy domain. We then present empirical data that compares the explanatory power of our appraisal–emotion approach with the two established psychological theories TPB and VBN in order to evaluate whether our approach can add explanatory value to the prediction of intentions to reduce energy use. Finally, we discuss how the appraisal–emotion approach may be fruitfully integrated with other existing approaches and outline some questions for future research.

THE RELATIONSHIP OF COGNITION AND EMOTION

Beginning with Plato, philosophers have often characterized the functioning of the human mind as a battle between opposing forces: reason, rational, and deliberate versus emotion, impulsive, and irrational (Goldie, 2010). This thinking has also been reflected in psychological theories and research on emotion: emotions were considered as interference that is counterproductive for a correct functioning of cognitive mechanisms, and thus perception, attention, memory, or decision-making were investigated without taking into account the effects of emotion. After a long time of neglect, however, the last two decades have seen an enormous increase in research on emotion highlighting the importance of emotional processes for a successful functioning of the human mind (Davidson et al., 2003; Sander and Scherer, 2009).

For example, neuropsychological studies have shown that patients with brain lesions that cause emotional dysfunctions can be highly impaired in everyday decision-making and social interactions (Damasio, 1994). These patients show inappropriate actions that lead to financial losses, to losses in social standing, and to conflicts with their family and friends. They also show a substantially reduced emotional reactivity to many types of events and a very limited interoception of their bodily responses, whereas their rational problem-solving abilities remain largely intact. These observations have led to the hypothesis that emotions may play an important role in shaping and guiding adaptive decisions. In a series of experiments, it has been shown that during their decision-making, these patients are not able to integrate emotional signals from the body that are triggered when one is about to make risky decisions (Bechara et al., 1997). These emotional signals are thought to represent learned experiences from previous decisions, which can be integrated to inform current choices, e.g., by helping to reject disadvantageous options (Bechara et al., 2005).

[1] Note that the perspective outlined here primarily addresses the individual citizen in his/her role as final user of energy.

The adaptiveness of emotional responses has furthermore been demonstrated in economic experimentations, where individuals participate in financial exchanges in small groups. In some of these economic games, a participant has the opportunity to spend some of his money to punish other participants for unfair behavior, such as failing to share a profit from a financial transaction. At the group level, these punishments are highly effective for keeping up fair interactions, and social groups whose members are willing to punish unfair behavior function much better in the long run (Fehr and Gachter, 2002). In order to punish, however, the punishing person has to sacrifice a part of his or her own profit, which is highly inconsistent with economic theories of utility maximization. Neuroimaging studies have shown that the observation of unfair behavior is accompanied by activation of the insula, a brain region involved in the experience of aversive emotional states (Sanfey et al., 2003), while a costly punishment of unfair behavior is associated with an activation of regions of the brain's reward system (de Quervain et al., 2004). This suggests that the perception of someone else's unfair behavior (that is beneficial for the individual, but damaging for the group in the long run) triggers aversive emotional responses, while punishing this behavior is perceived as rewarding even though it involves financial losses. These emotional reactions ensure long-term collaboration at the group level and are thus more "rational" than decisions that are purely based on economic utility maximization.

In parallel to these neuropsychological demonstrations, recent theoretical developments in emotion psychology have abolished the strong opposition of cognition and emotion, but instead emphasize that emotional and cognitive processes are strongly intertwined. Appraisal theories of emotion claim that emotions are elicited as the individual automatically and continuously evaluates the information in one's environment, scanning for information that is relevant to one's concerns, goals, needs, and values (Ellsworth and Scherer, 2003; Moors, 2010). Psychological and neuroimaging research has helped to specify the evaluation criteria that are involved in the appraisal process, showing that the appraisal process is composed of very rapid automatic low-level processes as well as slower, more deliberate processes that together evaluate any incoming stimulus regarding the following criteria: relevance (does this directly affect me), implications (what does it mean for my well-being), coping potential (can I deal with the challenge), and congruency with moral considerations (is this appropriate with regards to my values and personal norms; see, e.g., Grandjean and Scherer, 2008; Moors, 2010; Brosch and Sander, 2013a; Gentsch et al., 2013).

The integrated outcome of this appraisal process determines the type of emotional response that is elicited (Siemer et al., 2007). For example, an appraisal of a situation as threatening and uncontrollable will trigger a fear response including motivational changes (a tendency to withdraw), physiological changes (increases in heart rate), changes in expression (eyes wide open), and changes in one's subjective feeling (experiencing fear), thus mobilizing the resources required to escape from the situation. A key notion of appraisal theories is that, given that the emotion is elicited based on an analysis of the situation that takes into account the requirements of the situation and the coping potential of the individual, emotional responses will be adaptive in their fit to the situational challenge. To illustrate, in contrast to the previous example of a threat that is appraised as uncontrollable and elicits fear, an obstruction that is appraised as controllable will rather elicit an anger response consisting of a tendency to attack, an increase in blood pressure, contracted eyebrows, and the experience of anger (Kreibig, 2010), thus enabling the individual to remove the obstacle.

The detection of relevant environmental information furthermore leads to a fundamental reorganization of a number of cognitive systems in order to prioritize the processing of the relevant information. For example, emotionally relevant information is automatically privileged by our perceptual and attentional systems, thus allowing the information to be noticed rapidly and, once detected, become the focus of further processing and action (Vuilleumier and Brosch, 2009). Furthermore, emotional information is prioritized in memory. Memories of emotional events are encoded and consolidated more deeply, and have a persistence and vividness that other memories seem to lack (Phelps and Sharot, 2008). Given that they represent events that have been appraised as especially relevant (Montagrin et al., 2013), emotional memories may serve as useful guides for future behavior. Emotion thus operates as an adaptive filter for incoming information focalizing our cognitive processing on information that is relevant to our concerns, goals, needs, and values, and thus setting the stage for subsequent behavior.

As illustrated by the examples in the previous sections, emotions can be important drivers of our decision-making, over and above cognitive factors and computations of utility alone. Effects of emotions on decisions can occur at different time horizons. For example, an emotion that is elicited in a concrete situation may be used as indicator of the relevance of the situation and lead to an appropriate decision (e.g., the indignation elicited by seeing a heavily polluted pond may motivate you to immediately sign up for a donation to Greenpeace). Alternatively, your anticipation of a future emotion may impact on your decision between several options (e.g., when deciding whether or not to buy a hybrid car, you may think about the pride or satisfaction that the status related to owning such a car may elicit and weigh it against the potential disadvantages). These two influences are referred to as effects of immediate emotions and anticipated emotions, respectively (Han and Lerner, 2009)[2].

Two important points result from this review of current developments in the emotion literature: (1) emotions emerge from a rapid and automatic cognitive-affective analysis of the situational challenges as well as the individual's potential to deal with them, and thus very often are adaptive, intelligent responses that reflect useful information. (2) Emotions play a big role in human decision-making and hence drive behavior, and an analysis of appraisal patterns and emotional responses may yield important insights into individual choices and behaviors. While a consideration of affective processes may also be very informative for explaining energy-related decisions and behaviors, the most influential

[2]A third type of emotional effect on decision-making involves so-called incidental emotions, which are emotions that arise from factors not related to the decision at hand. For example, you refuse to make a donation to Greenpeace because you are angry about an unrelated discussion you had with your boss earlier.

theories used in this field so far do not consider these factors as important drivers of human behavior.

CURRENT THEORIES OF ENERGY-RELATED DECISIONS AND BEHAVIOR

The TPB (Ajzen, 1991) is the theoretical framework that is most widely used in attempts to explain individual energy-related decisions and behaviors. TPB assumes that a behavior is the consequence of a reasoned process that weighs the costs and benefits of the behavior. An individual's intention to perform a certain behavior (which is the most important predictor of the actual behavior) is thought to be determined by three main factors: the individual's *attitude* toward the behavior (reflecting the explicit evaluation of a behavior, based on a weighing of various costs and benefits such as financial costs, effort, time, and potential profit), the individual's *perceived behavioral control* (referring to the ease or difficulty with which the individual can engage in the behavior), and *subjective norm* (an individual's perception of the extent to which important social reference persons such as friends, family, or colleagues would approve or disapprove of the behavior as well as the individual's motivation to comply with these social pressures). TPB has been successfully used to predict and explain a wide range of behaviors, including energy-relevant behaviors such as energy savings (Harland et al., 1999) or choice of transportation (Bamberg et al., 2003). A meta-analysis of studies using TPB found that the factors postulated by the theory explained 39% of the variance of intentions and 27% of the variance of actual behaviors (Armitage and Conner, 2001). As a "rational choice" theory, TPB conceptualizes individual decisions as driven by cognitive processes underlying self-interested utility maximization, and does not consider affective processes or emotions as important drivers of decisions[3].

While TPB is centered on the maximization of self-interest (including conformity with subjective external norms), the VBN (Stern, 2000) and its predecessor, the norm activation model (NAM, Schwartz, 1977) have been developed with the explicit aim to explain altruistic behavior. According to NAM, behavior is driven by an individual's personal norms, referring to a feeling of moral obligation to perform a certain behavior. This moral obligation results from an awareness of a problem and its potential consequences as well as the belief that one can do something to avert these consequences. Based on this idea, VBN has been specifically developed to explain environmental behaviors. VBN proposes a causal chain of variables that has its starting point with an individual's *core values.* These values, which are broad representations of an individual's overarching goals, in turn determine an individual's environmental *beliefs*, which describe how an individual sees himself or herself in relation to the environment. Environmental beliefs are related to the extent to which individuals think that their own behavior can have negative consequences for the environment (*awareness of consequences*), which in turn determines whether an individual assumes responsibility for environmental problems (*ascription of responsibility*). Assumed responsibility results in the activation of a moral obligation to act (*personal norms*), which is positively related to the willingness and intention to act pro-environmentally. VBN has been used to successfully predict a number of environmentally related decisions and behaviors, such as intentions to reduce car use (Nordlund and Garvill, 2003) or to recycle (Guagnano et al., 1995). In general, its predictive power seems to be higher for intentions than for actual behaviors (Lindenberg and Steg, 2007).

The theoretical framework of the VBN with the postulated causal chain of factors emphasizes cognitive factors such as beliefs and norms. Affective processes or emotions are not explicitly included into the driving factors of decisions and behaviors. Interestingly, the VBN emphasizes the importance of core values, which play a key role in the elicitation of emotions (Nelissen et al., 2007) and their role in decision-making (Brosch and Sander, 2013b). Furthermore, personal norms, reflecting the moral obligation to act environmentally, are often assessed using items with an emotional content such as "I feel guilty when I use a lot of energy" (Abrahamse and Steg, 2009). Thus, at least implicitly emotions are included here, but their role is not explicitly spelled out in the theory.

Taken together, the two dominant psychological theories that are used to explain energy-related decisions and behavior are mainly centered on cognitive variables and mechanisms. TPB is a rational choice theory focusing on expectancy $\times$ value computations that maximize self-interest, while VBN is a normative theory combining value and belief systems into internal obligations about the "right thing to do." Given the recent advances in theorizing on emotion, we feel that it may be worthwhile to attempt an integration of affective processes into models that aim to explain energy-related decisions and behaviors.

AN APPRAISAL–EMOTION PERSPECTIVE ON ENERGY-RELATED DECISIONS AND BEHAVIORS

Energy-related decisions and behaviors are most likely driven by a combination of several different factors and motivations, including self-interested considerations (e.g., living in comfort, saving money), social and altruistic motivations (e.g., gaining other's approval, preserving resources for others and future generations), as well as ecological concerns (e.g., reducing damage to nature, see also Lindenberg and Steg, 2007). Appraisal theory holds that emotions reflect the integration of the relevance of an event or object in the context of a person's concerns, goals, needs, and values. Emotional processes and emotional experience may thus be an appropriate mechanism for the integration of several classes of motivational considerations (which may even be in conflict with each other).

Here, we propose a theoretical approach that integrates an analysis of cognitive appraisals concerning the relevance of energy conservation as well as emotions that are experienced in situations that are related to energy conservation. In order to develop a parsimonious, theory-driven approach, we based the model on a body of research on appraisal processes that has identified the psychological and neural mechanisms underlying the main classes of appraisals that play important causal roles in the elicitation of emotion (Ellsworth and Scherer, 2003; Brosch and Sander, 2013a),

[3]Even though a factor of the theory is labeled "attitude," a concept frequently used in emotion psychology, the attitude construct used in TPB is a very cognitive one, based on the weighing of the potential costs and benefits of the action ("How many positive and negative consequences do I expect from this behavior"), and as such very close to the economic concept of utility.

and specified the appraisal classes by adapting them to the thematic of energy conservation. The model thus predicts that the following appraisals are important for the elicitation of emotions as well as for the prediction of important individual differences in energy-related decisions and behaviors:

1. Relevance: To what extent am I affected by the problem of climate change?
2. Implication: How immediate is the impact of these changes on my life?
3. Coping potential: To what extent can I contribute to the prevention of these changes by saving energy?
4. Value-congruence: To what extent is energy conservation desirable in the context of my value hierarchy?

Different people will appraise the same situation differently as a function of their concerns, goals, needs, and values, and will thus react with different emotional responses to these situations. An individual's appraisal profile should predict the frequency and/or intensity of an individual's emotional reactions in relevant situations, such as pride when successfully conserving energy, or indignation when observing someone else waste energy. Finally, both the pattern of an individual's appraisal and the pattern of an individual's emotional reactivity in relevant situations should be useful predictors of an individual's intention to engage in energy-saving behaviors.

Our aims in this contribution are twofold: (1) to move toward a theoretical integration of cognitive and affective processes into models that are used to explain energy-related decisions and behaviors. Even though at least one psychological model widely used in applied research (VBN) already implicitly includes affective factors (such as values and moral emotions), the role of emotion is not explicitly included in most models. Here we aim at developing this theoretical integration, taking into account the most recent developments in emotion psychology. Importantly, we wish to move beyond the perspective of emotion as an "irrational interference," but to offer a clear integrative theory that describes the interplay of cognition and emotion and emphasizes the functional, adaptive aspect of emotional responses. (2) To empirically evaluate the potential contributions of our appraisal–emotion approach to the explication of individual intentions to reduce energy use, and especially to evaluate whether our approach can explain parts of the variance of individual decisions and behaviors that are not taken into account by mainly cognitive models focused on self-interest (TPB) or normative considerations (VBN), and thus may offer new and additional insight into the factors underlying energy-related decisions and behaviors that are consequential for a successful energy transition.

We compared the predictive power of three psychological theories that have postulated sets of variables in order to explain individual intentions to reduce energy use: the TPB, the VBN, and the appraisal–emotion approach introduced here. In the first step, we test the predictive power of each of the three theories separately. In the second step, we combine the different models using hierarchical regression analysis, to test whether the appraisal–emotion model can explain any additional variance, or whether the proposed factors are already sufficiently captured by the established models.

MATERIALS AND METHODS

PARTICIPANTS

A total of 168 students of the University of Geneva (146 females, 22 males, mean age: 22.1 years, SD: 4.6) participated in the study.

MEASUREMENTS

We designed a number of questionnaires to measure the key variables postulated by the different theories. Given that numerous studies already tested the degree to which TPB and VBN predict energy-related decisions and behaviors (see, e.g., Poortinga et al., 2003, 2004; Abrahamse and Steg, 2009, 2011), we adapted our measures from these publications.

Theory of planned behavior

Attitude toward energy conservation was measured using several semantic differential scales ("bad–good," "unnecessary–necessary," "positive–negative," "not fun–fun," "important–unimportant," and "useless–useful") that were combined into one score. Perceived behavioral control was measured by three items ("I know how I can save energy in daily life," "I find it difficult to reduce my energy use," and "I can reduce my energy use quite easily") combined into one score. Subjective norms were measured by combining two items ("My family members think it is important that I conserve energy" and "My close friends think it is important that I conserve energy") into one score. All responses were assessed using seven-point Likert scales.

Value-belief-norm theory

Participants' value priorities were measured using the Schwartz Value Inventory (SVI, Schwartz, 1992). Participants rated 57 items covering 10 different types of values (power, achievement, hedonism, stimulation, self-direction, universalism, benevolence, tradition, conformity, and security) on a nine-point scale from *opposed to my principles* (−1) through *not important* (0) to *of supreme importance* (7). Individual scores for the second-level value dimensions self-enhancement, self-transcendence, openness to change, and conservatism were then formed by averaging scores across the respective value types. Beliefs were assessed using the revised version of the new environmental paradigm (NEP, Dunlap et al., 2000) as well as five items measuring awareness of consequences ("The greenhouse effect is a problem for society," "The increasing energy demand is a serious problem for our society," "Energy conservation contributes to a reduction of the greenhouse effect," "The depletion of fossil fuels is a problem," and "Claims that we are changing the climate are greatly exaggerated," combined into a single score), and one item measuring ascription of responsibility ("I take joint responsibility for the depletion of energy resources"). Personal norms were assessed by three items: "I feel guilty when I choose a mean of transportation with high energy consumption (e.g., plane) even though there is an energy-friendlier travel option (e.g., train)," "I have a bad conscience when energy is consumed unnecessarily in the household (e.g., lights on in unused rooms)," and "I have a bad conscience when I buy, e.g., strawberries from South Africa in the winter instead on seasonal fruit from the region," combined into a single score). All responses were assessed using seven-point Likert scales.

Appraisal–emotion theory

We measured key appraisal and emotional variables pertinent to our appraisal–emotion approach with a newly developed set of items. Relevance appraisal was measured using the item "How close or distant do you feel as an individual to the problem of climate change (very distant/very close)?" Implication appraisal was measured using the item "How immediate is the impact of these ecological changes on your life (not at all immediate/highly immediate)?" Coping potential appraisal was measured using the item "To what extent can you contribute to the prevention of climatic change by reducing energy use (not at all/very much)?" Value-congruence appraisal was measured using the item "To what extent is energy conservation desirable from the perspective of your personal values (not at all desirable/highly desirable)?" All responses were assessed using seven-point Likert scales.

An individual's tendency to experience emotions in situations related to positive or negative ecological behavior was assessed with a series of items ("How often do you feel ashamed because you wasted energy?," "How often do you feel angry because you wasted energy?," "How often do you feel anxious of the consequences of global warming for our planet and its inhabitants?," "How often do you feel indignated because others waste energy?," "How often do you feel contempt because others waste energy?," "How often do you feel ashamed for others because they wasted energy?," and "How often do you feel proud because you have seen others conserving energy or avoiding wasting energy?"). All responses were assessed using five-point Likert scales (ranging from "never" to "very often") and combined into a single score.

Intentions to save energy

Finally, a set of items measured participants' intentions to engage in energy-saving behavior. Participants were presented with different energy-friendly behaviors (see **Table 1**, adapted from Poortinga et al., 2003; Poortinga et al., 2004), and indicated their intention to engage in the specific behavior using four-point Likert scales from 1 (not at all) to 4 (definitely). All responses were combined into a single score, where higher scores indicate stronger intentions to engage in energy-saving behavior.

Table 1 | List of energy-saving behaviors covered in the questionnaire (adapted from Poortinga et al., 2003; Poortinga et al., 2004).

Improve house insulation
Use energy-saving light bulbs
Buy more energy-efficient car
Insulate wall behind radiator with heat-reflecting foil
Install more energy-efficient heating system
Buy more energy-efficient refrigerator
Walking or cycling short distances up to 2.5 km
Switching off lights in unused rooms
Line drying of laundry (no dryer)
Do not leave appliances on stand-by
Take shorter showers
Rinsing the dishes with cold water
Walking or cycling distances up to 5 km
Go on holidays by train (instead of plane)
Using public transport
Buy seasonal fruits and vegetables
Set the thermostat to 18° maximally
Avoid eating meat

Table 2 | Regression results for the TPB variables to predict intentions to engage in energy-saving behavior ($N = 168$); β, standardized regression coefficient; *t*, *t*-statistic; R^2, total variance explained; *F*, *F*-statistic.

	β	*t*	R^2	*F*
Subjective norm	0.235	3.28**		
Perceived behavioral control	0.249	3.68***		
Attitude	0.304	4.39***		
Model			0.340	28.20***

****p < 0.001, **p < 0.01.*

RESULTS

A series of multiple regression analyses was conducted to evaluate the predictive power of the different theoretical approaches. In a first analysis, we used the variables postulated by TPB (attitude, perceived behavioral control, and subjective norm) to predict intentions to engage in energy-saving behavior (see **Table 2**). About 34% of the individual variance in these intentions could be explained by the TPB variables (very similar to the 39% average variance explained reported in the meta-analysis by Armitage and Conner, 2001). Congruent with theoretical predictions, participants with higher perceived normative pressure, higher perceived behavioral control, and more positive attitudes toward energy conservation had stronger intentions to engage in energy-saving behaviors.

In a second regression analysis, we used the variables predicted by VBN (core values, environmental beliefs, personal norms) to predict intentions to engage in energy-saving behavior (see **Table 3**). About 45% of the individual variance in these intentions could be explained by the VBN variables. Congruent with the theoretically predicted chain of variables (Stern, 2000), personal norms as the most proximal variable to actual intentions and behavior was the most powerful (and the only significant) predictor of energy-related intentions. Additional analyses confirmed the chain of variables predicted by the model: personal norms were strongly correlated with beliefs (NEP: $r = 0.36$, $p < 0.001$, awareness of consequences: $r = 0.35$, $p < 0.001$, ascription of responsibility: $r = 0.40$, $p < 0.001$), and beliefs in turn correlated strongly with core values (self-transcendence values correlated with NEP: $r = 0.28$, $p < 0.001$ as well as awareness of consequences: $r = 0.25$, $p = 0.001$; conservation values correlated negatively with NEP: $r = -0.24$, $p = 0.002$).

To test our appraisal–emotion approach, we then conducted a third regression analysis with the predictor variables relevance appraisal, implication appraisal, coping potential appraisal, value-congruence appraisal, and experienced emotions (see **Table 4**). About 39% of the individual variance in these intentions could be explained by the appraisal–emotion variables, with each individual

Table 3 | Regression results for the VBN variables to predict intentions to engage in energy-saving behavior ($N = 168$).

	β	t	R^2	F
Value: self-enhancement	−0.073	−0.73		
Value: self-transcendence	0.139	1.27		
Value: openness to change	0.115	1.23		
Value: conservation	0.029	0.27		
Belief: new environmental paradigm	0.101	1.42		
Belief: awareness of consequences	0.062	0.89		
Belief: ascription of responsibility	0.076	1.14		
Personal norms	0.468	6.46***		
Model			0.451	16.32***

****p* < 0.001.*

Table 4 | Regression results for the appraisal–emotion variables to predict intentions to engage in energy-saving behavior ($N = 168$).

	β	t	R^2	F
Relevance appraisal	0.157	2.0*		
Implication appraisal	0.126	1.95+		
Coping potential appraisal	0.242	3.33**		
Value-congruence appraisal	0.127	1.80+		
Experienced emotions	0.231	3.10**		
Model			0.394	21.02***

****p* < 0.001, ***p* < 0.01, **p* < 0.05, +*p* < 0.10.*

predictor variable reaching at least marginal statistical significance. Higher appraised relevance, more immediate appraised implications, higher appraised coping potential, higher appraised value congruency, and higher tendency to experience emotions in energy-related situations all independently predicted more intentions to engage in energy-saving behavior. Additional correlational analyses confirmed the postulated link between appraisals and emotions: each individual appraisal variable predicted increases in experienced emotion in energy-relevant situations (relevance: $r = 0.49$, $p < 0.001$, implication: $r = 0.25$, $p = 0.001$, coping potential: $r = 0.40$, $p < 0.001$, value congruency: $r = 0.43$, $p < 0.001$).

After having established the predictive power of each theoretical approach on its own, in a second step we performed a series of hierarchical regression analyses in order to evaluate whether the variables from the appraisal–emotion approach can explain additional variance over and above the two more established theories TPB and VBN. We first tested for the combined predictive power of the TPB and the appraisal–emotion variables (see **Table 5**). When controlling for the TPB factors (which on their own explained 34% of the variance, see above), appraisal–emotion factors explained a statistically significant additional 13% of the variance for a combined explained variance of 47%.

Table 5 | Hierarchical regression results for TPB (model 1) and the combined variables from TPB and the appraisal–emotion approach (model 2, $N = 168$).

	β	t	R^2	ΔR^2	ΔF
Model 1 (TPB)			0.340	0.340	28.16***
Subjective norm	0.235	3.28**			
Perceived behavioral control	0.249	3.68***			
Attitude	0.304	4.39***			
Model 2 (TPB and appraisal–emotion approach)			0.469	0.129	7.70***
Subjective norm	0.136	1.99*			
Perceived behavioral control	0.153	2.36*			
Attitude	0.179	2.61*			
Relevance appraisal	0.097	1.29			
Implication appraisal	0.092	1.48			
Coping potential appraisal	0.192	2.84**			
Value-congruence appraisal	0.023	0.29			
Experienced emotions	0.180	2.48**			

****p* < 0.001, ***p* < 0.01, **p* < 0.05.*

We then tested for the combined predictive power of the VBN and the appraisal–emotion variables (see **Table 6**). When controlling for the VBN factors (which on their own explained 45% of the variance, see above), appraisal–emotion factors explained a statistically significant additional 8% of the variance for a combined explained variance of 53%.

In a final analysis, we analyzed the three models together in one hierarchical regression model, with the TPB variables entered in the first step, the VBN variables entered in the second step, and the appraisal–emotion variables entered last (see **Table 7**). Adding the VBN variables to the TPB variables explained a statistically significant additional 17% of the variance. Importantly, adding the appraisal–emotion variables to the combined TPB–VBN variables led to another significant increase by 6% in the explained variance. Taken together, the variable sets from the three theories explained 57% of the variance in intentions to reduce energy use.

DISCUSSION

In this manuscript, we propose a framework that applies recent theoretical developments concerning the functionality of affective processes and emotions to the explanation of energy-relevant decisions and behaviors. Based on previous work investigating the impact of appraisal processes on the elicitation of emotion and their impact on decision-making (see, e.g., Damasio, 1994; Han and Lerner, 2009; Brosch and Sander, 2013a,b; Brosch et al., 2013), we proposed that a sparse set of variables consisting of appraisal criteria and emotional experiences in an energy-relevant context may help explain energy-related decisions and behaviors. We empirically investigated the explanatory power of the model variables to predict intentions to reduce energy use and compared the performance of the model to the two most frequently used theories. Initial analyses showed that the variable sets postulated by

Table 6 | Hierarchical regression results for VBN (model 1) and the combined variables from VBN and the appraisal–emotion approach (model 2, *N* = 168).

	β	*t*	R^2	ΔR^2	ΔF
Model 1 (VBN)			0.451	0.451	16.32***
Value: self-enhancement	−0.073	−0.73			
Value: self-transcendence	0.139	1.27			
Value: openness to change	0.115	1.23			
Value: conservation	0.029	0.27			
Belief: new environmental paradigm	0.101	1.42			
Belief: awareness of consequences	0.062	0.89			
Belief: ascription of responsibility	0.076	1.14			
Personal norms	0.468	6.46***			
Model 2 (VBN and appraisal–emotion approach)			0.533	0.082	5.42***
Value: self-enhancement	−0.047	−0.50			
Value: self-transcendence	0.161	1.56			
Value: openness to change	0.142	1.63			
Value: conservation	0.026	0.26			
Belief: new environmental paradigm	0.056	0.81			
Belief: awareness of consequences	0.043	0.64			
Belief: ascription of responsibility	0.041	0.66			
Personal norms	0.309	3.95***			
Relevance appraisal	−0.011	−0.14			
Implication appraisal	0.115	1.96+			
Coping potential appraisal	0.214	3.23**			
Value-congruence appraisal	0.016	0.24			
Experienced emotions	0.143	1.94+			

****$p < 0.001$, **$p < 0.01$, +$p < 0.10$.*

the TPB, the VBN, and the appraisal–emotion approach explain similar amounts of variance in intentions to reduce energy use. More importantly, we then showed that when combined in hierarchical regression analyses, the appraisal–emotion variables are able to account for additional variance that is not explained by the established models. This indicates that appraisal and emotion processes may contribute to energy-related decisions over and above considerations based on self-interest maximization and normative concerns. The increase in explained variance was especially pronounced when combining the appraisal–emotion

Table 7 | Hierarchical regression results for TPB (model 1), the combined variables from TPB and VBN (model 2), and the combined variables for TPB, VBN, and the appraisal–emotion approach (model 3, *N* = 168).

	β	*t*	R^2	ΔR^2	ΔF
Model 1 (TPB)			0.340	0.340	28.20***
Subjective norm	0.235	3.28**			
Perceived behavioral control	0.249	3.68***			
Attitude	0.304	4.39***			
Model 2 (TPB and VBN)					
Subjective norm	0.078	1.15	0.479	0.173	6.95***
Perceived behavioral control	0.194	3.08**			
Attitude	0.144	1.91+			
Value: self-enhancement	−0.064	−0.66			
Value: self-transcendence	0.098	0.91			
Value: openness to change	0.125	1.40			
Value: conservation	0.018	0.17			
Belief: new environmental paradigm	0.047	0.65			
Belief: awareness of consequences	0.070	1.01			
Belief: ascription of responsibility	0.002	0.03			
Personal norms	0.374	5.17***			
Model 3 (TPB and VBN and appraisal–emotion approach)			0.566	0.053	3.68**
Subjective norm	0.060	0.91			
Perceived behavioral control	0.141	2.25*			
Attitude	0.126	1.71+			
Value: self-enhancement	−0.047	−0.50			
Value: self-transcendence	0.127	1.25			
Value: openness to change	0.148	1.71+			
Value: conservation	0.014	0.14			
Belief: new environmental paradigm	0.022	0.31			
Belief: awareness of consequences	0.048	0.72			
Belief: ascription of responsibility	−0.011	−0.01			
Personal norms	0.275	3.6***			

(Continued)

Table 7 | Continued

	β	*t*	R^2	ΔR^2	ΔF
Relevance appraisal	−0.023	−0.31			
Implication appraisal	0.089	1.54			
Coping potential appraisal	0.187	2.88**			
Value-congruence appraisal	−0.029	−0.44			
Experienced emotions	0.131	1.81⁺			

****p* < 0.001, ***p* < 0.01, **p* < 0.05, ⁺*p* < 0.10.*

variables with TPB, a rational choice theory based on the pursuit of self-interest. But also when combining the appraisal–emotion variables with VBN, which implicitly includes concepts related to affect and emotion, additional variance was explained. Finally, even when controlling for the impact of all variables postulated by TPB and VBN together, the appraisal–emotion variables were still able to explain additional variance in individual intentions to reduce energy use[4]. Taken together, these findings suggest that affective processes and emotions, which have been shown to substantially increase our understanding of a number of different decision processes (Han and Lerner, 2009; Brosch and Sander, 2013b; Brosch et al., 2013), may also constitute a powerful factor determining individual decisions and behaviors in the energy domain.

Intuitively, it should not come as too much of a surprise that the vast spectrum of human decisions and behaviors relevant for the energy consumption of a society (see **Table 1** for just a small list of examples) is not only driven by strictly cognitive considerations, but also involves automatic and affectively colored processes. And indeed, some attempts have already been made to more explicitly integrate emotions into psychological theories of environmental behavior (e.g., Triandis, 1977; Kals et al., 1999). However, far less use is made of these theories in current research and intervention development than that made of the two dominant theories TPB and VBN. It may thus be fruitful to attempt an integration of the notion that affective processes and emotions are a valuable source of information for individual decision-making with existing models that focus on other drivers of decisions and behavior, such as the incentive structure of the situation, individual self-interest, or normative considerations. By combining recent insights about the functionality of emotions with already existing approaches, this perspective may become more interesting for scientists from other academic traditions and potentially also for policy makers searching for effective interventions. Interdisciplinary integration is highly desirable for tackling a problem as complex and important as the behavior change necessary for a successful energy transition, as approaches that are rooted within the conceptual boundaries of one discipline can only hope to capture a small part of the whole process.

Energy-related decisions and behaviors are driven by a combination of different factors and motivations that need to be weighed and balanced. For example, a person who chooses a very high standard of living requiring intense energy consumption will experience immediate personal benefits (life comfort), while in the long run causing disadvantages both for the individual and at the group level (need for high energy production, potential energy shortages, environmental damage). However, giving up on a high standard of living to save energy will initially lead mainly to personal disadvantages (loss of comfort), with positive outcomes experienced by society only in the long run. The immediate incentive structure thus will not motivate a self-interested individual to reduce energy consumption (as long as the energy prices are held constant). Nevertheless, recent economic work has demonstrated that individuals are actually willing to sacrifice their immediate benefits in order to promote behavior that is beneficial for the group in the long run (Fehr and Gachter, 2002). Importantly, neuroimaging results indicate that the trade-off of immediate individual gain for the long-term advantage of the group is driven by neural regions involved in the experience of reward and emotions (Sanfey et al., 2003; de Quervain et al., 2004). These results not only indicate the potential importance of considering emotions in the governance of public goods such as unmined energy resources and clean air, but also open up a path for the integration of energy conservation into classic economic perspectives: emotional reactions may actually add utility value to energy conservation. The appraisal–emotion model specifies a sparse set of appraisals that underlie the elicitation of individual emotional responses in the energy domain. It may be a promising approach to develop interventions targeting the specific set of appraisal criteria proposed here. Modifying an individual's appraisal of the implications of energy overconsumption, for example through targeted information provision campaigns, may change his/her emotional response, which may in turn increase the utility value for certain decision options, either via immediate emotions or anticipated emotions. This may be an avenue to integrate affective processing and emotions into economical and psychological rational choice models based on utility and self-interested considerations such as the TPB.

Normative models such as the VBN already include core values, which play an important role in the elicitation of emotions (Nelissen et al., 2007; Brosch and Sander, 2013a) and their role in decision-making (Brosch and Sander, 2013b), as well as moral emotions such as guilt or shame that serve to motivate the normative function of social constraints. In this perspective, environmental-friendly behavior seems to be conceptualized as "morally correct" behavior, that is, people save energy to avoid violating a social norm, resulting in real or imagined social disapproval and feelings of guilt. Affect motivates decisions and behaviors insofar as individuals are trying to prevent negative outcomes. However, that is only "half the truth" about the motivating function of emotions. Emotions also motivate to promote positive outcomes, strive for reward, attain goals, and self-actualize (Higgins, 1998). Thus, a more complete integration of affective processes into this kind of theory may capitalize on the full range of human emotions. Interventions may aim at combining

[4]Note that even with the most complete model, a substantial portion (43%) of the individual variance in behavioral intentions to reduce energy use remains unaccounted for. Additional psychological (e.g., implicit biases, personality traits) or non-psychological (e.g., socio-economic status, individual situational constraints) factors that were not assessed in this investigation may furthermore contribute to the formation of individual behavioral intentions.

desired behaviors both with positive incentives that individuals want to attain and with negative outcomes that individuals want to prevent. For example, information campaigns or advertising campaigns for energy-efficient products may include material that emphasizes the positive emotions resulting from environmentally responsible behavior (e.g., pride), while also mentioning the potentially aversive consequences of environmental damage.

A perspective that considers emotions as yielding useful, "rational" information may furthermore fruitfully be linked to approaches from behavioral economics that focus on heuristics and cognitive biases and their impact on decision-making. In fact, at least two heuristics that are central to this perspective can be linked to affective processing. The *affect heuristic* describes the observation that an individual may substitute an initial affective reaction for a thorough analysis of the situation (Finucane et al., 2000). For example, participants who were asked to evaluate the potential risks and benefits of nuclear energy showed a strong negative correlation between their risk and benefits judgments, especially when acting under time pressure, which was interpreted as the impact of a rapid affective response to the evaluated stimulus that participants used to inform both kinds of judgments. The *availability heuristic* refers to the fact that information that is easily retrievable from memory is especially influential during a decision process (Tversky and Kahneman, 1973). Whereas both types of heuristics are usually discussed in a dual process framework that opposes intuitive/affective responses to rational thought, we have outlined above that recent psychological and neuroscientific research suggests a revision of this perspective (e.g., Damasio, 1994). Even rapid affective responses based on fast, automatic appraisal processes may contain useful information that can improve decision-making, and thus should not be opposed to rational processes (see Brosch, 2013, for a more detailed discussion). Furthermore, it has been shown that information that has previously been appraised as relevant for one's concerns is prioritized in memory and thus more easily retrievable (Montagrin et al., 2013). As such, it seems highly adaptive that information that was relevant in the past should have a larger impact on current decision-making (Phelps and Sharot, 2008). Interventions that aim at nudging people toward desired outcomes (Thaler and Sunstein, 2008) should take into account the possibility to leverage rapid automatic appraisal processes by appropriately framing the decision situation. For example, in a recent study household energy use was reduced and kept below average by combining information about consumption patterns with minimal affective information (a smiley face for households using less than average energy, see Schultz et al., 2007).

Thus, taking into account affective processes and emotions related to energy conservation (or the lack of energy conservation) may not only substantially increase our understanding of the mechanism that underlie individual decisions and behaviors related to energy use, but may also be successfully integrated with and complement other existing perspectives in the behavioral sciences, contributing to the interdisciplinarity that is required for the development of efficient interventions.

One qualification of the work presented here is that the evidence supporting the appraisal–emotion model so far is based exclusively on self-report measures, i.e., participants were asked to report their appraisal structure and to remember their emotional experience in relevant situations. This is problematic both for methodological and conceptual reasons. At the methodological level, participants may have been prone to a number of response biases that come with the self-report format. For example, participants may have been motivated to respond in a manner that will be viewed favorably by others and thus exaggerated their intentions to reduce energy use, or in a manner coherent with their personal theories about emotion and thus exaggerated the link between appraisals, emotions, and decisions. However, this problem is shared by most empirical research in this field, which, given the variables that researchers are interested in, is strongly based on self-report and questionnaire data. An important next research step will be to link individual appraisal structures and emotions not only to intentions to reduce energy use, but also to objective measures of actual behavior (e.g., actual energy use). At the conceptual level, psychological and neuroimaging research has shown that the appraisal process occurs very rapidly and in a partially automatic fashion (Grandjean and Scherer, 2008; Brosch and Sander, 2013a). Thus, not all aspects of the appraisal process are necessarily accessible to introspection and can be reported in a questionnaire. The aspects of appraisal that reach consciousness may only represent the "tip of the iceberg" (Scherer, 2005). This issue needs to be tackled by combining multiple methods over and above self-report, such as the measurement of energy-related appraisal processes at the neural level and an assessment of the different components of the emotional response as it occurs, including physiological responses and elicited action tendencies.

Considering automatic affective processes in energy-relevant situations may furthermore vastly improve our understanding of the mechanisms underlying habits, automatized behaviors which are also very important determinants of energy use (Marechal, 2009), but are driven by mechanisms different from the ones underlying more deliberate decision-making (Aarts and Dijksterhuis, 2000). Thus, complementing standard self-report measures with implicit tasks and neuroimaging methods seems an especially promising approach to develop more complete models of energy-related decision-making and behavior and may well become the future gold standard.

To sum up, in this contribution we argue for an integration of affective processes and emotions into the study of energy-related decisions and behavior. In contrast to theories that consider emotions as "irrational interference," we emphasize that cognitive and affective processes are closely intertwined. Emotional responses represent important information about the relevance of an object or situation for an individual's concerns, goals, needs, and values. They may thus play an important and adaptive role in driving individual decisions and behaviors, over and above considerations of utility, beliefs, and behavioral norms. A sparse set of factors assessing an individual's appraisal processes and emotional response patterns with regards to energy-relevant situations can predict a sizeable amount of variance in intentions to reduce energy use. Importantly, a comparison with two established models shows that the appraisal–emotion approach can explain variance over and above models focusing on self-interest and normative considerations, respectively. We argue that affective processes and emotions can and should be integrated into other theoretical perspectives developed within the behavioral sciences that are important in research on energy use. Energy-related decisions and behaviors are manifold. A thorough understanding of the underlying mechanisms requires the simultaneous consideration of the decision situation with its specific incentive structure, the decider with his or her beliefs, values, appraisals, and emotions, and the type of decision, ranging from highly deliberate informed choices to habitual behaviors.

A better understanding of the factors influencing individual energy-related decisions and behaviors is important for a successful energy transition, and thus of high societal interest. Over the last two decades, the "affective turn" has fundamentally changed the way psychologists and neuroscientists think about emotions, their adaptive function, and their role in decision-making. We hope that the research and the open questions outlined here will contribute to an integration of these ideas into research on one of society's fundamental problems.

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Energy-using durables – why consumers refrain from economically optimal choices

Renate Schubert* and Marcel Stadelmann

ETH Zürich, Zürich, Switzerland

Edited by:
Tobias Brosch, University of Geneva, Switzerland

Reviewed by:
Kenneth Gillingham, Yale University, USA
Hannes Weigt, University of Basel, Switzerland

****Correspondence:***
Renate Schubert, ETH Zürich, Clausiusstrasse 37, 8092 Zürich, Switzerland
e-mail: schubert@econ.gess.ethz.ch

Sustainable development requires increasing the energy efficiency, decreasing the growth rates of energy demand, and decreasing the CO_2 emissions. In many countries, households' energy consumption is responsible for a considerable share of total energy demand and CO_2 emissions. Energy-using durables are essential in this context. Aiming at sustainability, private households should buy more energy-efficient durables and use them in a more efficient way. In principle, it might even be economically optimal to buy the more energy-efficient products, since they result in lower total costs over their lifetime – thus resulting in a positive net present value (NPV). However, when observing private households' purchase decisions, they often do not correspond to the economic optimum, resulting in an "energy-efficiency gap." This paper investigates into the reasons for the persistence of such a gap between energy-efficient products that would be economically optimal – but from which consumers refrain – and less energy-efficient products that consumers actually own or buy although they entail larger life-cycle costs. Factors, which seem to deter private households from purchasing energy-efficient products with positive NPVs, are, for example, insufficient information, limited attention, or inertia. We will show how these and other factors hinder private households from identifying and realizing their economically optimal choices and how such barriers can be overcome. We will present how properly designed energy labels could help to overcome the information-related causes of inefficiently low energy-efficiency investments and provide some additional policy recommendations that could help reaching the aforementioned goal of a reduction of households' energy demand and CO_2 emissions in an adequate way.

Keywords: energy-efficiency gap, sustainability, insufficient information, limited attention, uncertainty of energy savings, inertia, energy labels, behavioral economics

1. INTRODUCTION

According to the latest reports of IPCC (Intergovernmental Panel on Climate Change) the scientific evidence reveals that the probability for men-made global climate change is very high (IPCC, 2014). The reports show that more than half of the CO_2 that is already stored in the atmosphere had been released during the last 40 years. The (future) negative consequences of global climate change can be described more and more precisely and the CO_2 amount that can still be emitted until 2050 without endangering the 2°C goals has to be limited to a maximum of 750 Gt worldwide. It also turns out that climate policy will not be for free but that, on the other hand, it seems feasible to save the planet. There will be reductions in growth rates, but overall, positive growth rates will persist. Hence, the conclusion from these reports is that we should act and that it is affordable to act. The sooner we act, the more affordable it will be.

There are recommendations on how to act to prevent dangerous climate change for all different levels, like, for instance, the aggregate level of country-wide policies or the micro level of individual households. In this paper, we are especially interested in measures adequate for a reduction of CO_2 emissions in private households. The motivation behind is the fact that more than 50% of total current CO_2 emissions stem from private households (including mobility) (Wiki Bildungsserver, 2013; BAFU, 2014). Mobility, electricity consumption, as well as heating or cooling of buildings are the key areas in which CO_2 is released. This at least holds for households in developed countries, which is the reason why we will focus on such countries. There are essentially two ways to decrease individual households CO_2 emissions in these countries. One would be to reduce the number and intensity of CO_2 emitting uses, the second one would be to make the single uses less energy-intensive and hence, given that most energy uses still have fossil components, less CO_2-emitting. Since the first way just mentioned might be related to serious welfare losses, we will concentrate on the second way, i.e., on measures to increase the energy efficiency of different uses. Hereby, we will limit our analysis to energy-using durables, leaving the analysis of infrastructural components like heating or cooling systems to further papers. Energy-using durables are typically responsible for about 80% of a private household's energy demand and for about 15–20% of their CO_2 emissions (BAFU, 2014; CSR Academy, 2014; Energybrain, 2014; Euresa, 2011).

Looking at energy-using durables like washing machines, fridges, coffee machines, TVs, computers, etc., we observe that in most developed countries a variety of product types with differing degrees of energy efficiency and differing prices are available. Only in some countries and for some products, government regulation forbids the sale of less energy-efficient product types. Comparing purchase prices plus current electricity costs for different types of one and the same product over the product's lifetime, it turns out that, taking into account a specific discount rate, it might be economically optimal to buy the more energy-efficient products. As a rule, these products will be sold at higher purchase prices. However, the lower current electricity costs throughout the whole lifetime of the product may outweigh the higher purchase prices. In economic terms, the net present value (NPV) of the more energy-efficient appliances will be higher than the NPV of the less energy-efficient appliances. Private households should hence be interested in buying energy-efficient durables with a higher NPV. Yet, one observes empirically that this is often not the case (see section 2). Many private households do not buy the appliances that would seemingly be economically optimal for them. This of course raises the question of why this is the case, i.e., why private consumers behave in a seemingly non-rational way.

In the literature, this phenomenon is well-known under the label of the "energy-efficiency gap." This gap consists of the discrepancy between energy-efficient or technologically efficient products that would be economically optimal – but from which consumers refrain – and less energy-efficient products that consumers actually own or buy although they entail larger life-cycle costs. From a purely methodological point of view, identifying this gap is not an easy task and the existing studies are of only limited value, due to their often short-sighted assumptions about economic optimality and time discounting. The literature discusses possible reasons for this discrepancy, which we will present in section 2.

In section 3, we will then have a closer look at causes that might be responsible for the economically non-optimal behavior of consumers when purchasing energy-using durables. Most of these causes are information-related in one way or the other. So, we will discuss insufficient information, limited attention and perception biases, the uncertainty bias, inertia and social network aspects and, finally, liquidity constraints. Based on this discussion of reasons for the existence of an energy-efficiency gap, section 4 is then dedicated to possibilities of overcoming barriers to technologically and economically efficient household investments. Given the close relation of all principal causes to the aspect of information, we will focus on information format and disclosure types in this section. Energy labels, especially those for household appliances, will hence constitute the key example used in section 4. Section 5 will be used for drawing conclusions on how to cope with the apparent discrepancy between alleged economic optimality and factual behavior of private households. We will end our paper with some policy recommendations that could help reaching the aforementioned goal of a reduction of households' energy demand and CO_2 emissions in an adequate way.

2. INSIGHTS FROM LITERATURE

Since the early 1990s, a situation in which households' investments in energy-efficient appliances seem to be lower than privately optimal has been referred to as the energy-efficiency gap or energy-efficiency paradox (Hirst and Brown, 1990; Jaffe and Stavins, 1994). Investment also – or even more so – seems to be lower than socially optimal, but it is the private sub-optimality of investment that legitimates the term "paradox" from an economic perspective (see Jaffe et al., 2004 for a discussion of different optima related to energy efficiency). The suggested lack of investment in energy efficiency leads to a gap between actual and optimal energy use (Jaffe and Stavins, 1994). The paradox lies in the slow diffusion of apparently cost-effective and energy-efficient technologies (Shama, 1983). Many households seem to ignore the opportunities of positive NPV investments in high-efficiency durables – judged by a reasonable market interest rate to calculate the present value of cost savings (Howarth and Stanstad, 1995). They either delay the replacement of low-efficiency products or settle for a low-efficiency product when purchasing an energy-using durable.

The energy-efficiency gap has become an increasingly popular topic in policy discussions because its reduction promises "win–win" opportunities. First, it allows reducing the negative externalities involved in current energy use, such as climate change, nuclear disasters, or dependencies on fuel imports. Switzerland, for example, imports 66% of its energy used, mostly in the form of fossil fuels, with major consequences for the environment, foreign policy, and the economy (Pomper, 2014). Second, other forces such as imperfect information may cause households not to undertake privately profitable investments in energy efficiency (Allcott and Greenstone, 2012). These forces present investment inefficiencies that lead to the "[...] Energy Efficiency Gap: a wedge between the cost-minimizing level of energy efficiency and the level actually realized" (Allcott and Greenstone, 2012, p. 4). Establishing the existence of an energy-efficiency gap would therefore justify large-scale policy intervention targeted at closing the gap. In order to select the right tools for possible policy interventions, it is essential to identify the potential cause(s) of an energy-efficiency gap – an issue addressed in this article. In fact, many public policies have already been implemented to stimulate energy efficiency, leading to an extensive literature on energy efficiency and conservation policy evaluation (for reviews of this literature, see, e.g., Gillingham et al., 2006; Tietenberg, 2009; Abrahamse et al., 2005).

Several studies by McKinsey & Company (Creyts et al., 2007; Granade et al., 2009; McKinsey & Company, 2009a) and others (see, for example, Chandler and Brown, 2009; EPRI, 2009; National Academy of Sciences, 2009; Rosenfeld et al., 1993 for a meta-analysis of earlier studies) suggest that certain investments in energy efficiency could indeed result in net monetary savings for households and thus improve economic efficiency. In these cases, the present discounted value of future energy savings would exceed the upfront costs of investments in energy-efficient equipment and appliances at current energy costs and thus have a positive NPV. Hence, such investments would not only help to reduce energy demand, thanks to their technological efficiency, but would also be economically efficient.

In their study about the energy-efficiency potential in the U.S. economy, Granade et al. (2009) in their base case apply a 7% discount rate as the cost of capital, use industrial retail rates as a proxy for the value of energy savings, and assume a zero price of carbon. Under these assumptions and for the current state of technology, they identify an energy saving potential of $1.2 trillion at an upfront cost of $520 billion (not including program costs) through 2020, pointing toward a potentially large energy-efficiency gap in the U.S. economy. There have been a limited number of such studies trying to estimate the economic potential of energy efficiency in Switzerland (see, e.g., McKinsey & Company, 2009b; Infras & TNC Consulting, 2010; McKinsey & Company, 2010; BFE, 2007). Infras & TNC Consulting (2010) provide an NPV estimate of CHF 7.6 billion until the year 2035 for energy-efficiency investments that would also be economically efficient. Hereby, they assume a constant interest rate of 2.5% and electricity prices increasing by 4% per 5-year period. However, such engineering estimates of the energy savings potential from seemingly cost-effective investments suffer from two major flaws: (1) the large sensitivity to the respective assumptions, such as the assumed discount rates or energy prices, and (2) the insufficient consideration of the household's perspective in the energy-efficiency investment decision (Gillingham and Palmer, 2014). Hence, in order to assess the economics of energy-efficiency investments, it is necessary to analyze consumer choices. This will be done in the following.

Attempts to empirically trace the existence of inefficient investment in energy efficiency in consumer choices date back to the 1970s and 1980s, when a considerable number of studies estimated the discount rates implicit in actual purchase decisions of energy-using durables. The rate of time discounting implicitly applied by a consumer who is indifferent between some smaller earlier payment and some larger later payment is called the "implicit discount rate." Epper et al. (2011) provide a simple stylized example of the method to estimate implicit discount rates (p. 2): suppose a consumer is indifferent between two products, a high-efficiency product H with a purchase price p_{H} and running costs c_{H}, all accruing in $t = 1$, and a low-efficiency product L with price p_{L} and running costs c_{L} with $p_{\mathrm{H}} > p_{\mathrm{L}}$ and $c_{\mathrm{H}} < c_{\mathrm{L}}$. Assuming linear utility and equating the present value of total costs $p_{\mathrm{H}} + c_{\mathrm{H}}\exp(-\vartheta)$, yields an implicit discount rate of $\vartheta = -\ln \frac{p_{\mathrm{H}} - p_{\mathrm{L}}}{c_{\mathrm{L}} - c_{\mathrm{H}}}$.

Table 1 summarizes the estimates of product-specific implicit discount rates until 2010 (as presented in Epper et al., 2011, p. 2).

DEFRA (2010) observes that (p. 15):

- there is a wide range of discount rates, from 2 to 300%, both within and across categories;
- most of the discount rates are considerably higher than market interest rates;
- discount rates are lower when saving energy is the primary purpose of the investment.

Table 1 | Estimated product-specific implicit discount rates p.a.

Category	Discount rate (%)
Thermal insulation	10–32
Space heating	2–36
Air conditioning	3.2–29
Refrigerators	39–300
Lighting	7–17
Automobiles	2–45

Sources: Train (1985); DEFRA (2010).

Ever since the seminal publication by Hausman (1979), the second observation has been connected to attempts of quantifying an energy-efficiency gap. The difference between the implicit discount rates (see **Table 1**) and market interest rates (for example, the 2.5% used by Infras & TNC Consulting, 2010), which we call the "discounting gap," often proves to be large. Hence, households are not willing to undertake energy saving investments with positive NPV, based on a current market interest rate for present value calculations. Discount rates in the range of 39–300%, as estimated, for example, for the purchase of refrigerators, imply that households might massively undervalue future energy savings as opposed to the initial purchase price. This would lead to a slower diffusion of energy-efficient refrigerators than could be expected if households realized all positive-NPV investments (Gillingham and Palmer, 2014). Therefore, the presence of a discounting gap has commonly been ascribed to irrational purchase decisions by households – and thus as proof of an energy-efficiency gap.

However, this inference is premature. In order to value the rationality of households' purchase decisions, the market interest rate used to assess the discounting gap needs to be adjusted for the uncertainty about the future benefits of the energy-efficiency investment, which will be discussed in the next section. Additionally, the implicit discount rates estimated in most discrete choice models are a mix of households' rates of time preferences and other factors that make it seem as if they were part of the time preferences, as, for example, unobserved utility components. Along these lines, Jaffe et al. (2004) challenge the appropriateness of implicit discount rates estimated in energy-conservation investment decisions to prove the existence of an energy-efficiency gap (p. 87):

> To observe that implicit discount rates are high, however, says nothing about the reason people make the decisions they make. One possibility is that people are applying normal discount rates in the context of significant market failures; another possibility is that people actually utilize high discount rates in evaluating future energy savings. [. . .] Thus, high implicit discount rates, on their own, are neither a market failure nor an explanation of observed behavior.

While the size of the energy-efficiency gap might thus have commonly been overestimated, there are several market failures and systematic behavioral biases in consumer decision making that suggest that the gap is real. These explanations of an energy-efficiency gap are elaborated in the following section.

3. WHY DO CONSUMERS REFRAIN FROM ECONOMICALLY OPTIMAL CHOICES? BARRIERS TO ECONOMICALLY RATIONAL BEHAVIOR

In this section, we will analyze in detail some of the reasons that could explain the existence of the so-called energy-efficiency gap. Hereby we assume that there are energy-using durables on the market, which are highly energy efficient and which, at the same time, are preferable from an economic point of view. If, under such circumstances, households do not buy the technologically and economically better appliances, something must prevent them from making choices, which are in their best interest. These barriers will now be looked at in detail.

3.1. INSUFFICIENT INFORMATION

The first interesting barrier to economically rational decisions of private households on energy-using durables is insufficient information or knowledge. Many decision makers know very little about the short-term and, in particular, the long-term economic consequences of using a specific type of an energy-using durable. At the same time, possibilities to gather such information exist and this information is often not even costly, which limits the contention that decision makers might rationally be inattentive or informed incompletely (see, e.g., Gabaix, 2014; Sallee, 2014 for models of rational inattention). These possibilities are, however, rarely used – due, in part, to some general inertia in decision making, which will be discussed in more detail later in subsection 3.4 (Loewenstein et al., 2001; Weber, 2006). Another reason for refraining from collecting the information that would be necessary in order to make decisions, which are in one's own best interest, is the fact that in most countries, the sums at stake are rather small. Given the low electricity prices, the monetary savings achievable through technologically and economically efficient appliances are not decisive for most households. Hence, the incentives for collecting additional information are rather low. Furthermore, even the societal advantage of buying more energy-efficient durables and making a contribution to the mitigation of climate change seems not to incentivize decision makers for compiling more information to compare the different types of a specific product like, for instance, a fridge. The negative consequences of global warming appear very distant to many people, in terms of geography as well as in terms of time; the issues seem to be intangible and unimaginable and hence unimportant for many decision makers (Leiserowitz et al., 2006; Lorenzoni and Pidgeon, 2006; Leiserowitz, 2007; Lorenzoni et al., 2007).

Yet, one could argue that private households should not actively search for information but should be provided – and in fact are provided – with the relevant information by suppliers, agencies, utilities, etc. However, much of the available information is accessible from or distributed through channels that are not practical or not relevant for many actors. If the goal is to achieve a better level of information among the masses, a first step could consist in employing the same media that decision makers use in their daily lives. Nowadays, it appears that the most effective media are those with a network character, such as Facebook, Twitter, WhatsApp, etc. The main advantage of channeling information through these media is that they are highly frequented by actors for other purposes as well, so that the actors do not have to incur additional costs to gather information about the technological as well as economic advantages of energy-using durables. Although there seems to be a tendency that such channels become more and more important, there is still a lot of information available only in conventional forms, hereby reducing the likelihood to be taken into account.

A further aspect is the information format. It seems important to present the information in different ways to the various target groups. If a target group is addressed in a "suitable" manner, chances of their actual involvement with the topic rise substantially. Possible forms of presentation include texts or films, comics or games, newspaper articles or scientific publications, simple and concrete illustrations that the reader can easily relate to or more abstract ones, quantitative or qualitative illustrations, and so on. An illustrative example of the expanding range of conceivable methods of communicating and informing are websites that calculate individuals' ecological footprint (Wackernagel and Beyers, 2010). They allow website visitors to see what multiple of Earth's resources would be necessary in order to sustain an entire world population using resources to the same extent as they do themselves. This could make decision makers aware of the importance of making decisions which at the same time are advantageous for themselves and for the society as a whole, hence combining technological and economic efficiency when buying appliances. Further examples include mobile applications that compute the CO_2 emissions associated with a shopping list or the presentation of the content of a scientific publication in the form of a graphic novel (Hamann et al., 2013). Depending on the relevant target group (children or adults, students or working population, men or women, etc.), the presentation of the information should be conceptualized differently in order to turn purchase decisions into well informed decisions, paving the way to individual and societal optimality.

The insufficient knowledge of many actors also manifests itself in the fact that they are not aware of their current energy costs and are not able to mentally categorize potential savings in this area (Thaler, 1985). Moreover, many actors are not even aware of how they could adapt their lifestyle in order to behave in a more sustainable, i.e., for example, more energy-efficient way (Gardner and Stern, 2008; Larrick and Soll, 2008; Attari et al., 2010). In other words, many decision makers have no correct ideas about which of their uses is related to a higher or a lower level of energy demand or to a higher or lower amount of monetary expenses.

Most actors are cognitively unable to perform cost–benefit analyses or to calculate option values, i.e., the value of future courses of action. These skills in turn would be necessary for making economically rational decisions. Furthermore, it is also worth noting that actors often refrain from informing themselves at all because they fear uncomfortable or negative components of this information, and tend to try to avoid this type of information (Cerulo, 2006; Norgaard, 2006). In a similar manner, actions with possible negative consequences are often avoided, even if the total potential benefits of an action would exceed its total potential costs (Bostrom et al., 2012).

Overall, the adequacy and accessibility of information seem to play an important role. At the same time, the cognitive and emotional skills of many private decision makers seem not sufficiently trained in order to search for and deal with the relevant information. Providing suitable information poses a challenge to scientists as well as firms and government institutions. One step toward this end may be, for example, to reduce the number of labels indicating environmental and energy-related effects of the consumption of specific goods. An additional step would be to also limit the amount of information which each of the remaining labels convey. A reduction of information to a comprehensible and manageable amount would matter. More details concerning ways to overcome information-related barriers for purchasing technologically and economically efficient household appliances will be discussed in section 4 of this paper.

Besides the information provision, decision makers' capabilities to search and process relevant information would have to be strengthened. As already mentioned, this must comprise cognitive as well as emotional aspects. Improvements in environment-related education could be one element in this context.

If the already existing information can successfully be made accessible and understandable and thus be used more in actors' decision making, this could help both to eliminate uncertainties and to improve the information's credibility. In addition, if more convincing examples of a strong long-run orientation of actors could be perceived throughout society, a closing of the energy-efficiency gap could be reached more easily. This is due to the fact that adapting to a behavior that is "common" in society is typically more attractive than swimming against the stream (for more details, see subsection 3.4).

3.2. LIMITED ATTENTION AND PERCEPTION BIASES

Since Simon (1955), who proposed a model of bounded rationality, it has been suggested that individuals simplify complex decisions, for example, by processing only a subset of information. Gabaix and Laibson (2006) analyze pricing with boundedly rational consumers who do not pay attention to hidden features of product prices, which they refer to as "add-on" costs. This finding is supported by recent empirical evidence that people are inattentive to ancillary product costs such as sales taxes (Chetty et al., 2009), shipping and handling charges (Hossain and Morgan, 2006), or out-of-pocket insurance costs (Abaluck and Gruber, 2011).

DellaVigna (2009) presents a simple model of attention as a scarce resource (p. 349):

> Consider a good whose value V (inclusive of price) is determined by the sum of two components, a visible component v and an opaque component o, $V = v + o$. Due to inattention, the consumer perceives the value to be $\widehat{V} = v + (1 - \theta)o$, where θ denotes the degree of inattention, with $\theta = 0$ as the standard case of full attention. The interpretation of θ is that each individual sees the opaque information o, but then processes it only partially, to the degree θ. The inattention parameter θ is itself a function of the salience $s \in [0,1]$ of o and of the number of competing stimuli $N: \theta = \theta(s,N)$. Based on the psychology evidence, I assume that the inattention θ is decreasing in the salience s and increasing in the competing stimuli $N: \theta'_s < 0$ and $\theta'_N > 0$. Inattention is zero for a fully salient signal: $\theta(1,N) = 0$.

Hossain and Morgan (2006) examine eBay auctions where the bidding price of an item is more vivid than the shipping costs, as the shipping costs are not part of the bidding process and not listed in the item title. In order to assess the effect of ancillary costs, they compare a situation without shipping costs (c_{LO}) to a treatment condition where the shipping costs represent the bulk of total costs (c_{HI}). In terms of the model introduced above, v is the value of the item and o is defined as the negative shipping cost: $o = -c$. In treatment c_{LO}, Hossain and Morgan (2006) auction CDs with a \$4 reserve price and no shipping cost, while in treatment c_{HI}, they auction CDs with a \$0.01 reserve price and a \$3.99 shipping cost. The change in reserve price guarantees that the two auctions are equivalent for a fully attentive bidder. The average revenue raised in treatment c_{HI} is \$1.79 higher (\$10.16 vs. \$8.37) than in treatment c_{LO}, and is higher for 9 out of 10 CDs. These estimates imply substantial inattention: $\widehat{\theta} = \frac{1.79}{3.99} = 0.45$. A second set of auctions with higher shipping costs ($c_{LO} = \$2$ and $c_{HI} = \$6$), leads to a smaller increase of revenues in the high shipping cost condition (\$12.87 vs. \$12.15), corresponding to an inattention parameter $\widehat{\theta} = \frac{0.72}{4} = 0.18$. These results prove that consumers' attention to ancillary product costs is indeed limited, especially when the size of the ancillary costs is relatively small compared to the purchase price of the item.

In the context of energy-using durables, the "shrouded" attribute is the running energy cost while the initial purchase price is much more salient. When buying energy-using durables such as cars, air conditioners, and light bulbs, households might thus be more attentive to the purchase price than to the running energy costs, leading to a higher weight of the former in purchase decisions. As presented in the empirical example above, the inattention to the energy costs is especially pronounced if they are small compared to the purchase price, as is the case for household appliances like, for example, refrigerators or washing machines. Therefore, due to inattention, households are less likely to purchase the more energy-efficient product that commonly entails a higher purchase price and lower running energy costs. This effect has been widely suggested in the theoretical literature as a potentially important driver of an energy-efficiency gap (see, e.g., Blumstein et al., 1980; Anderson and Claxton, 1982; Jaffe and Stavins, 1994; Sanstad and Howarth, 1994; and many others).

Empirical evidence for limited attention in the context of energy-using durables is scarce, but it seems very likely that the effects observed in other contexts are applicable to energy-using durables, especially if the energy costs are low relative to the purchase price. In an artifactual, computer-based field experiment, Allcott and Taubinsky (2014) assess the effect of an information treatment on the purchase of compact fluorescent light bulbs (CFLs) as opposed to incandescent light bulbs. They find a positive effect of the information intervention on the purchase of the energy-efficient CFLs. They try to disentangle how much the information treatment affected choices through increased attention vs. updated beliefs. While the wide dispersion in beliefs does not allow for a clear picture, Allcott and Taubinsky (2014) suggest that both factors contribute to the treatment effect, thus maintaining that limited attention is relevant in keeping households from buying CFLs.

Other sources for decision makers' limited attention are different perception biases. Limited attention may be due to the fact that the relevance of energy efficiency is not present in decision makers' subjective experience (e.g., because of very low monetary expenses for electricity) or because this topic is not sufficiently addressed in the media (e.g., the consequences of continued usage of appliances with low energy efficiency are hardly described). In this context, one often speaks of the so-called "availability bias." This bias causes people to perceive especially strong information that they are already familiar with or information that is mentally available, while not (or hardly) perceiving other information. An effect is mentally available if an individual is able to readily and easily imagine or recall the effect. Some phenomena seem to stick especially well in an actor's memory, namely if the actor has witnessed them first-hand or has access to lively recounts of others (Jungermann et al., 2005, pp. 173). Examples of the availability bias involving environmental issues in general as well as climate change in particular include the 2007 floods in England or the film *The Day After Tomorrow*. Both of these instances led to a temporarily very high awareness for environmental threats. However, the shocking effect of such events or accounts diminishes after only a few months and usually entirely vanishes after around 1 year.

Some effects are also strongly perceived because decision makers infer causalities. If a hot summer is explained as a result of climate change, decision makers' perception of climate change is very strong. This effect is also known as the "representativeness heuristic," which owes its name to the idea that an underlying phenomenon (climate change) is deduced from an individual event (hot summer) that is seen as representative for a group of events (Jungermann et al., 2005, p. 170).

Furthermore, events contradicting theories and beliefs actors hold are perceived especially strongly as well. If a very cold winter occurs, this event does not seem to fit into the general theme of global warming; so decision makers take particular notice of it. According to the representativeness heuristic, a very cold winter may be interpreted as indicating the absence of global warming. Because this interpretation contradicts a nowadays commonly held opinion, the phenomenon receives special attention. Studies show that focusing on climate change as a driver of change in the observable natural environment of households increases the households' willingness to adapt their behavior toward more sustainable, e.g., more energy-efficient behavior (Alberini et al., 2013, p. 75).

3.3. UNCERTAINTY BIAS

Purchasing a more energy-efficient durable typically encompasses larger certain initial costs than a less efficient alternative while being related to lower but uncertain running energy costs over the lifetime of the product. A biased perception of the uncertainty about future framework conditions such as the price of energy or the amount of energy saved often leads decision makers to refrain from purchasing the more energy-efficient and economically rational alternatives (Hassett and Metcalf, 1993; Metcalf and Hassett, 1999). If it is uncertain, for example, what the prices for electricity will be over the next 5, 10, or 20 years, or if it is unclear which technological and social innovations will emerge in the areas of housing and private consumption in the next 5, 10, 20, or 30 years, this can undermine investments targeting a more efficient use of energy. Purchase decisions which, for a given set of parameters, seem rational and economically efficient, might not be efficient under differing future conditions.

Greene (2011) presents a model that demonstrates how the perception of uncertainty can lead to a bias – the "uncertainty-loss aversion bias" (ULAB). Due to the uncertainty about the value of future energy savings, the range of possible net values of the investment might also embrace the loss domain compared to the current *status quo*. If potential losses weigh more heavily in an investment decision than potential gains – as loss aversion would suggest (see, e.g., Kahneman et al., 1991) – the possibility of a potential loss could prevent some consumers from making the investment (Greene, 2011). Uncertainty coupled with loss aversion thus contributes to a "*status quo* bias" because the disadvantages of change are weighted more heavily than its advantages or chances (Anderson, 2003; DEFRA, 2010). This effect could be highly relevant for explaining an energy-efficiency gap. If private households expect, for example, decreasing electricity prices or totally new types of household appliances for the future, they may be reluctant to buy more energy-efficient durables today, even if these products are technologically and economically efficient under current conditions.

Irrespective of their economic effectiveness, energy-efficient appliances may require behavioral changes when using them. Using energy-saving shower heads, for instance, changes the way in which people shower. Decision makers may face substantial uncertainties about possible future returns to their behavioral changes like reduced monetary costs, increased reputation, etc. As compared with such uncertain benefits, the costs of behavioral change may seem overly high; a behavioral change and hence the underlying purchase of an energy-using durable may be considered as too risky and may be avoided by a decision maker affected by the ULAB. It has been shown, for example, that house owners who are in principle considering a renovation of their house to increase its energy efficiency often end up refraining from such a renovation if they are unsure about the development of future energy prices (Alberini et al., 2013). In order to promote behavioral changes toward economically optimal and energy-efficient investments, better information and protection with respect to future (cost-) developments should be provided so that the private households' uncertainty can be reduced. Notably, information about future developments can often only be provided in terms of probabilities. Yet, many people have trouble understanding and working with the concept of probability. At least for younger generations, this highlights a clear educational task while it might also help to provide the probabilistic information in terms of a frequency format rather than a percentage format (Cosmides and Tooby, 1996).

Another aspect of insufficient knowledge and uncertainty stems from the uncertainty about the behavior of others. If private households do not know how other households in their surroundings or networks will act, they are often not willing to change their behavior in a way that may have (short-run) negative consequences for themselves. Such negative consequences could, for instance, be the higher immediate purchase prices of appliances. Irrespective of the economic efficiency, private households may refrain from buying technologically and economically efficient durables because they are afraid that they will be the only ones carrying the higher initial costs, while everyone else will benefit from their behavior, i.e., from their investment in energy-efficient products (*Prisoners' Dilemma*, Kerr, 1983). The willingness to proactively enter such a scenario is understandably low, but should in many cases be significantly higher to induce behavioral changes toward more energy-efficient investments. Only if many other decision makers were to change their behavior as well and buy more energy-efficient products with high initial purchase costs and low lifetime current costs would there be a noticeable impact (Larrick and Soll, 2008).

3.4. INERTIA, SOCIAL NETWORKS, AND SOCIAL NORMS

A further barrier to purchasing technologically and economically efficient household appliances lies in the inertia of decision makers or their aversion toward change, labeled the *status quo* bias above (Epstein, 1999). Many decision makers shun the costs associated with change, which is why they do not change their electricity supplier or tariff despite knowing better, forgo renovations of their houses and apartments to make them more energy-efficient, or do not buy new energy-using durables, which might be advantageous from an individual as well as from a societal point of view. Inertia also restrains people from replacing older, less energy-efficient appliances which are still functioning through new appliances with higher technological and economic efficiency. Inertia can in some cases be explained by the fact that people fear making decisions that they may regret later on; for example, if future energy prices turn out differently than was expected when making a decision (Zeelenberg et al., 2002).

Inertia or the avoidance of costs incurred through behavioral change appears to be especially large when the behavioral change is not accompanied by a social compensation, e.g., reputation in society or special appreciation in friend circles. In this context, therefore, social networks play an important role (Abrahamse and Steg, 2009). For one, decision makers can use these social networks to receive appreciation for their energy-efficiency efforts. In addition, they can use the social networks to convince themselves that they are not the only ones making an effort for energy efficiency. The exchange of specific tips and hints can possibly even make individual investment efforts more efficient and effective. Given the experience and insights of their friends, private households may be able to better understand that buying energy-efficient appliances may not only be advantageous for the society as a whole but also for themselves, on an individual level, with respect to long-term economic profitability. The role of experts or scientists in such networks is ambiguous. On the one side, experts could prove to be conducive with respect to both, information about impacts related to various energy-using durables as well as experience related to prior purchase decisions. However, the presence of experts may also deteriorate the trust potential within the network. Empirical evidence on the respective importance of both effects is still missing.

Related to the social compensation through social networks is also the effect of role models. If individual decision makers see athletes, actors, business people, politicians, or other people, they look up to behave in a certain way, for example, drive smaller cars or purchase household appliances with high technological and economic efficiency, this will often induce an imitative effect. This imitative effect will be stronger the more knowledge about the role models' behavior and the more support for the imitative behavior stems from the individual's social network (Tsakas, 2012). Thus, private households might buy energy-efficient appliances with the hope of hereby attaining social status and appreciation (Bird and Smith, 2005; Griskevicius et al., 2010).

Social norms prevailing in groups relevant for the decision makers prove to be crucial to how efficiently they handle their energy consumption (Schultz et al., 2007; Handgraaf et al., 2013). When complying with social sustainability norms of the relevant group, private households may be rewarded by a so-called warm-glow effect (Andreoni, 1990, 1995), i.e., they might receive positive utility not only from the consumption of a private good like an electronic device but also from the contribution to a public good, e.g., climate change mitigation. This means that even if decision makers would not recognize the individual economic advantage, they could obtain when buying technologically and economically efficient appliances that they might decide for the purchase of an energy-efficient appliance due to the related public good contribution and the respective altruistic utility. Furthermore, in general, social conformity increases most individuals' utility whereas social disapproval typically generates disutility due to other individuals' negative reactions to one's own behavior (Masclet et al., 2003; Bicchieri, 2006). Hence, given the dependence of households' utility on complying with social norms, measures shaping such norms in favor of high energy efficiency to be "cool" and "a must" might result in closing the energy-efficiency gap.

The above mentioned inertia is, among others, a reason why decision makers are susceptible to nudges (Thaler and Sunstein, 2008). Today, in several countries, nudges are observable in various areas like, for instance, organ donation, pension savings schemes, or electricity tariffs (Elektrizitätswerk der Stadt Zürich , EWZ). For the context discussed here, the idea would be to present economically efficient appliances as default options in a choice architecture. Decision makers can opt out of this default option and explicitly choose a less sustainable alternative instead. Studies have shown, however, that due to the inertia of decision makers, opting out is rather rare. This suggests that defaults or nudges might be an interesting way to promote widespread sustainable behavior (Dinner et al., 2011; Allcott and Mullainathan, 2010). A successful example related to purchasing energy-efficient and long-term economically profitable products is the furnishing of new buildings in the US with energy-saving light bulbs by default (Dinner et al., 2011).

The nudge approach is occasionally criticized for being paternalistic and imposing on individuals what they should choose to do. Empirical studies suggest, however, that nudges may rather help individuals follow strategies that they prefer anyway. For example, the number of actual kidney donations differs substantially between Germany, where not donating is the default option, and Austria, where donating is the default option (Nationaler Ethikrat, 2007). It can be assumed that the actual willingness to donate a kidney is similar in both countries. A further notable advantage of the nudge approach is that it can be employed not only by the government but also by private firms, for instance, by suppliers of energy-using durables.

Nudges might be especially useful because they reduce the decision-making costs for private households. Decision makers often need to incur high costs to gather enough information for a behavior-altering decision (information is dispersed, sometimes paradoxical and incomplete, etc., see subsection 3.1), and many individuals thus avoid the process of seeking information. Instead, they decide from the onset to keep away from the cognitive effort associated with the gathering of information, and stick to their previous behavior (Iyengar et al., 2006; Fasolo et al., 2009; Alberini et al., 2013). Here, the *status quo* bias mentioned above also kicks in. Nudges can help in this situation precisely because they help individuals with a certain willingness to change their behavior to do so without having to perform a large cognitive or general prospecting effort.

Finally, another form of inertia manifests itself in the fact that individuals often increase their sustainable behavior with regard to some resources, but simultaneously reduce their sustainable behavior with regard to others. An explanation that might be relevant for the context of purchasing energy-using durables is the so-called moral licensing effect (Mazar and Zhong, 2010). The moral licensing effect describes a situation in which a private household overall behaves in a rather environmentally friendly way, for instance, by refraining from car-driving or traveling by plane. Then, these consumers may have the impression that they have invested enough effort into fostering sustainability and that there is no need to purchase energy-efficient appliances with high purchase prices. This may hold even in case of economically efficient appliances as long as the economic efficiency is not noticed (see, e.g., subsection 3.2).

It is possible that the moral licensing effect is based on the so-called single action bias (Weber, 1997). According to this bias, often only one single change of behavior is made, for example, the general switching off of the standby-mode, without any additional energy saving or efficiency-increasing behavioral changes. Decision makers often already achieve a clear conscience through one action, and further behavioral changes are no longer perceived as necessary. This effect is also closely related to the "finite pool of worry" effect (Weber, 2006), which states that the behavioral changes caused by concern about climate change or limited natural resources are not infinite. If one is especially concerned about one area (for example, about the CO_2 emissions caused by flying), one tends to be less concerned about other areas (for example, about the energy efficiency of household appliances) and not to change one's behavior in these other areas.

The exchange in social networks can help abate these effects, for example, if it becomes clear that the other members of the social network make sustainability efforts in some areas without making downward adjustments elsewhere. The minimum level of sustainability individuals seek to achieve can be influenced by the respective norm in the individual's social network and can thus be moved up or down (Schultz et al., 2007; Kotchen and Moore, 2008; Baeriswyl et al., 2011).

3.5. LIQUIDITY CONSTRAINTS

A further important reason for the gap between the availability of technologically and economically efficient appliances und households' factual purchase decisions lies in households' liquidity constraints (Golove and Eto, 1996). Even if households might wish to purchase the economically efficient energy-using durable, they are often not able to afford these options financially. This issue mainly arises because most energy-efficient appliances are characterized by higher initial investment costs and lower operational costs than less energy-efficient appliances. The high upfront costs have to be financed, which can fail due to the lack of personal financial resources and a lack of willingness or opportunities to take on debt. It is also possible that households' liquidity constraints are not factual but only perceived due to a limited financial budget for household appliances. This separation of monetary funds into different mental accounts violates the fungibility virtue of money and thus represents a type of behavioral bias called "mental accounting" (Thaler, 1985).

Actual liquidity constraints and the perception of an unfavorable relationship between benefits and costs or risks of sustainable behavior are often closely linked. In economically rather limited situations, risks and costs of energy-efficient investments are often overestimated, while their benefits tend to be underestimated, especially if the decision makers have a rather short-term perspective. Additionally, a liquidity constrained decision maker is more likely to possess preferences for the present so that the likelihood of long-run oriented purchases of energy-using durables is low. If one is able to make information about the private and societal benefits of technologically and economically efficient appliances more accessible and more credible, this could contribute to more energy-efficiency investments in spite of liquidity constraints. The integration of such information into private households' social networks could make a significant contribution in this context.

Furthermore, new business models could help reduce the liquidity requirements of decisions in favor of energy-efficient and economically rational durables and thus make this barrier less important. For example, with energy providers charging a higher monthly fee for newly bought efficient household appliances over a longer period of time instead of charging a relatively high purchase price once, one would support individual "purchase" decisions that could close the energy-efficiency gap. Such models already exist, for instance, within the area of investments into heating or cooling systems for individual property houses (Schläfli, 2012). These business models could be promoted using policy instruments, as for example, tax rebates or exemptions. Such models would help low-income households to enlarge their portfolio of feasible purchases of energy-using durables and could result in more durables' purchases which at the same time foster individual economic well-being as well as societal (environmental) welfare.

4. OVERCOMING THE BARRIERS: THE EXAMPLE OF ENERGY LABELS

Since energy-using durables can be used over a relatively long period without being depleted, the respective purchase decisions are rather complex and cognitively demanding. They have a long time horizon, requiring estimates on running costs for several years into the future. Such decisions present a challenge for many households, which is why availability, perception, and processing of information play an important role. Allcott and Greenstone (2012) even state (p. 19): "Imperfect information is perhaps the most important form of investment inefficiency that could cause an Energy-Efficiency Gap." In this section, we thus focus on information problems to exemplify the policy implications of the energy-efficiency gap (for a broad discourse about policy responses to barriers to energy efficiency, see, e.g., Gillingham et al., 2009; Tietenberg, 2009; Gillingham and Palmer, 2014).

Allcott and Taubinsky (2014) always mention imperfect information in combination with limited attention (p. 3): "[...] we focus on imperfect information and inattention because results from other literatures suggested that these two distortions could be large, [...]." Any information intervention can serve both to eliminate imperfect information and to direct the attention of households toward subsets of information that they were previously inattentive to. Therefore, Allcott and Taubinsky (2014) state (p. 3): "It is thus not unreasonable to assume that our information treatment is what we call a pure nudge: it informs all previously uninformed consumers and draws full attention to energy costs, with no other effects." In their artifactual field experiment of light bulb purchases, Allcott and Taubinsky (2014) find that the information treatment reduces both imperfect information and inattention, and thus increases purchases of the more energy-efficient CFLs.

In real world, labels portray an established instrument for information disclosure. In the context of energy-using durables, energy labels are a policy instrument used in many countries. There are several, mostly hypothetical studies analyzing the effects of different energy label formats on households' purchase decisions. Rohling and Schubert (2013) provide a thorough review of the literature on energy labels for household appliances. They show that a variety of energy-efficiency labels exist around the globe. The aim of such labels is to influence consumers' purchase decisions for household appliances by making them more energy-efficient. The way in which these labels are designed differs significantly. While some labels display details of a product's energy consumption in physical units (kilowatt hours), other labels focus on monetary units (for instance US$). Most energy labels currently applied globally accumulate a product's energy use over the period of 1 year, while the energy consumption for a single use or for the product's expected lifetime could be alternative information presentation formats. The way in which information is presented matters since it directly impacts consumers' purchase decision. Larrick and Soll (2008) show that labels may even enhance less energy-efficient decisions if the presented information is not perceived properly (*MPG Illusion).*

As visualized in **Figure 1**, energy labels can be divided into two categories: *endorsement* labels and *comparative* labels (see Wiel and McMahon, 2005). *Endorsement* labels are essentially "seal-of-approvals" that are applied only to the most energy-efficient models of a specific product class or to model meeting certain sustainability criteria. Most endorsement labels are voluntary.

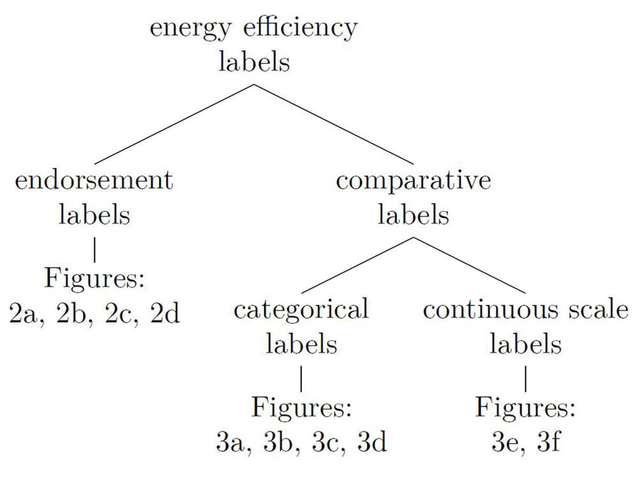

FIGURE 1 | Types of energy-efficiency labels.

The probably best known endorsement label, the ENERGY STAR, was launched in 1992 in the US and is now also applied in many other countries such as most European countries, Canada, Australia, Japan, New Zealand, and Taiwan (see **Figure 2A**). The label identifies energy-efficient products in more than 40 categories, including major office equipment products, heating and cooling equipment, lighting, home electronics, buildings as well as plants. Other endorsement labels are, for example, the Chinese Energy-Conservation Certificate (see **Figure 2B**), the Recognition-type Energy Label in Hong Kong (see **Figure 2C**), or the High-efficiency Appliance Certification in South Korea (see **Figure 2D**). Endorsement labels typically do not contain much information (Banerjee and Solomon, 2003). Since seal-of-approvals do not provide any product-specific information on energy consumption, no differentiation with respect to energy efficiency is possible among the labeled products.

Comparative labels, the second category of energy labels, provide a solid comparison of household appliances in terms of their energy efficiency. In most countries around the globe, comparative labels are mandatory: several household appliance categories are required to display such a label. Currently, labels follow two different approaches: labeling with categories (bar or dial/gage) and labeling with a continuous linear scale. In the first approach, products are put into different energy-efficiency categories. The labels allow a comparison of appliances across, but not within each energy-efficiency category. This approach is, for example, used for the EU Energy Label (see **Figure 3A**). From 1994 onward, retailers were required to display this label on new refrigerators, freezers, washing machines, and some other products like ovens or water heaters (European Parliament, 1992). The label originally had seven energy-efficiency categories A–G, with A being the best. In addition to the letter grades, energy-efficiency categories are visualized by bars of different color and length: green and short for A, red and long for G.

The energy-efficiency category that a product is assigned to is indicated by a black arrow located next to the colored bar. Since 2010, three new categories A+++, A++, and A+ were added for refrigerating appliances, washing machines, and dish washers to respond to significant energy-efficiency improvements of these products (European Parliament, 2010). The design of the EU energy label is also used by several other countries, among them Switzerland, Brazil, Iran, Tunisia, and China (see **Figure 3B**).

Australia and similarly Japan, Thailand, South Korea, and India categorize electronic devices on a dial or gage (see **Figures 3C,D**). Depending on the product, five to seven stars rather than bars indicate a product's energy-efficiency category. A product's energy class is visualized by the number of stars that are highlighted in color, the more the better. In the second approach, a continuous linear scale displays the range of energy consumption between the most (left end of the scale) and least (right end of the scale) efficient appliance with similar product features. A product's relative performance is indicated by a small black arrow above the scale, the further left the better. Information on the product's energy use or energy costs, respectively, is attached to the black arrow. This format, which allows a direct comparison of energy consumption between appliances of even similar efficiency levels, is used for the US EnergyGuide and the Canadian EnerGuide (see **Figures 3E,F**).

FIGURE 2 | Endorsement labels – (A): ENERGY STAR, (B): Chinese Energy-Conservation Program, (C): Recognition-type Energy Label, (D): South Korean High-efficiency Appliance Certification Program.

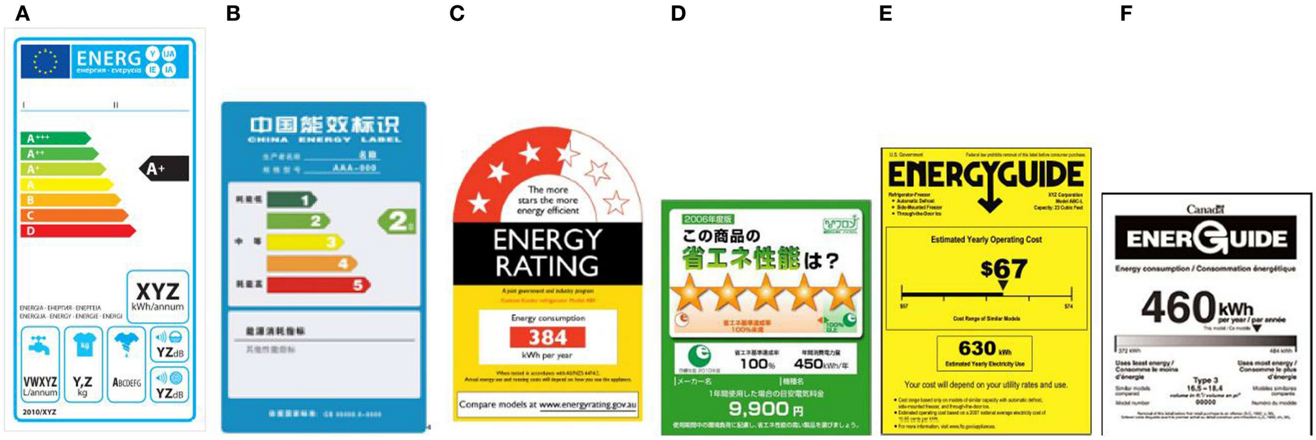

FIGURE 3 | Comparative labels – (A): EU Energy Label, (B): Chinese Energy Label, (C): Australian Energy Label, (D): Japanese Energy Label, (E): US EnergyGuide, (F): Canadian EnerGuide.

Currently, comparative labels not only differ with respect to their visualization of energy efficiency, i.e., categorical vs. continuous scale labels but also in their way of *presenting* information on energy consumption. The EU Energy Label, for example, provides several types of physical information, e.g., kilowatt hours/annum or water (in liters) per year. However, no information in monetary units is disclosed on this label. By contrast, the US EnergyGuide displays estimated yearly operating costs, i.e., monetary units, in the center of the label, while physical units are placed less prominently. The order of priority was reversed as part of a redesign of the label in 1994. However, since 2005 energy operating costs have again been placed in the center of the label. A new generation of labels has been introduced by the U.S. Environmental Protection Agency in 2011 for vehicles. It combines annual physical and monetary with an estimate of fuel costs over 5 years compared to the average new vehicle (EPA, 2011). The energy label used in Japan displays both economic and physical information, with yearly operating costs being placed more prominently. No unambiguous empirical evidence exists on whether monetary rather than physical units are advantageous for impacting customers' purchase decisions. Advantages of providing monetary figures are that money is a widely used unit with a clear meaning for consumers. Monetary indications may provide economic incentives to reduce energy consumption and hence to purchase more energy-efficient appliances (McNeill and Wilkie, 1979). On the other hand, energy prices differ remarkably within the European Union or the US. Therefore, monetary units on the energy label might provide misleading information for consumers' purchase decisions.

Interestingly, irrespective of the fact whether monetary or physical units are displayed, all labels accumulate the respective information over the time period of *1 year*. For specific product classes, like, for instance, washing machines, averaged annual data over several years may provide meaningful information. However, no label provides information on expected life-cycle energy consumption or costs. Since consumers typically perceive information as more important when a larger number is indicated (see, e.g., Camilleri and Larrick, 2014; Burson et al., 2009), presenting life-cycle information might strengthen the case for energy-efficient appliances. Yet, providing life-cycle information is no easy task and requires several assumptions, e.g., on product lifetime or discount rates, which may be contested.

In their literature review on empirically measured effects of different energy-efficiency label formats on consumers' purchase decisions, Rohling and Schubert (2013) find that energy labels might indeed impact households' purchases of energy-using durables. However, which label format is best for guiding households' choices toward more energy-efficient products remains disputable. Their synthesis shows that neither presenting energy use in monetary units nor in physical units was unambiguously relevant. Implications of presenting lifetime instead of annual information of a product's energy use were more consistent. The impact of labeling proved to be stronger when the information of energy use provided was accumulated over the product's expected lifetime. These effects, however, tend to be small and, at least in some studies, are not significant. Thus, while no unambiguous recommendation can be given as to whether monetary or physical units ought to be disclosed, lifetime information tends to have a stronger effect on energy-efficient purchases than monthly or yearly data.

On the other hand, it should be noted that the empirical evidence on the effect of the energy label on households' purchase decisions of energy-using durables is still rather sparse and dominated by hypothetical experiments and surveys. There are very few studies of actual purchase decisions, as for example, by Anderson and Claxton (1982) or Kallbekken et al. (2013). Additional studies on the effects of different energy label formats on households' purchase decisions of energy-using durables are thus desirable.

5. CONCLUSION

It turns out that there are several reasons why private households refrain from purchasing energy-efficient appliances even if it would be advantageous for them from an economic point of view. Hence, by providing economic incentives, private households' energy demand cannot be reduced as strongly as it would be possible if this energy-efficiency gap did not exist. Attempts to close the energy-efficiency gap would provide "win–win" opportunities: (1) private households could profit from lower running energy costs if they purchased economically efficient energy-using durables, and (2) societies on an aggregate level could mitigate climate change while moving toward more independent and secure energy systems.

It is thus highly relevant to identify the reasons for the persistence of the energy-efficiency gap in order to enable the design of targeted policy interventions. These reasons lie essentially in information-related problems like insufficient information, limited attention, and uncertainty bias as well as in psychological factors like inertia on the one hand and social networks and social norms on the other hand. The third relevant category consists in households' liquidity constraints, which might be factual or perceived constraints.

From a policy perspective, it seems most worthwhile to primarily tackle the information-related reasons for the persistence of the energy-efficiency gap. Such measures seem to be highly cost-efficient. One possibility is hence to promote and design energy labels in a way that helps to convey the information of economic optimality to households. Concerning the other factors hindering energy-efficient investments, liquidity constraints – especially the factual ones – could be overcome by exempting households in need from some of the investment costs that would have to be raised in order to purchase energy-efficient appliances. The psychological factors seem to be the most problematic when trying to close the energy-efficiency gap. They require a lot of refinement in choice architecture surrounding purchase decisions with respect to energy-using durables because factors like social norms cannot be easily set or altered by regulating agencies. It seems as if more research efforts would be needed in this area. On the other hand, one might suppose that already accepting the relevance of social norms and of social networks would bring some success. Innovation in the area of social networking is required. Some approaches like, for instance, using firms as catalytic for informing their employees about the economic optimality of more energy-efficient appliances in their private homes, are already in sight and seem quite promising (Pan European Networks, 2014).

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When Push Comes to Shove: Compensating and Opportunistic Strategies in a Collective-Risk Household Energy Dilemma

Anya Skatova[1,2]*, *Benjamin Bedwell*[1] *and Benjamin Kuper-Smith*[1,3]

[1] Horizon Digital Economy Research, University of Nottingham, Nottingham, UK, [2] Warwick Business School, University of Warwick, Coventry, UK, [3] Institute of Neurology, University College London, London, UK

To solve problems such as climate change, every little push counts. Community energy schemes are a popular policy targeted to reduce a country's carbon emissions but the effect they have on energy use depends on whether people can work together as a community. We often find ourselves caught in a dilemma: if others are not doing their bit, why should I? In our experiment, participants ($N = 118$) were matched in groups of 10 to play in a collective-risk game framed as a community energy purchase scheme. They made only one decision about energy use for their virtual household a day, while a full round of the game lasted 1 week in real time. All decisions were entered via personal phone or a home computer. If in the end of the week the group exceeded a pre-paid threshold of energy use all group members would share a fine. Each day participants received feedback about decisions of their group partners, and in some groups the feedback was manipulated as high (unfair condition) or low (fair condition) use. High average group use created individual risk for participants to be penalized in the end of the week, even if they did not use much themselves. We found that under the risk of having to pay a fine, participants stayed significantly below the fair-share threshold regardless of unfair behavior of others. On the contrary, they significantly decreased their consumption toward the end of the game. Seeing that others are doing their bit – using a fair-share – encouraged people to take advantage of the situation: those who played against fair confederates did not follow the normative behavior but conversely, increased their consumption over the course of the game. These opportunistic strategies were demonstrated by impulsive participants who were also low in punishment sensitivity. We discuss the findings in the light of policy research as well as literature on cooperation and prosocial behavior.

Keywords: cooperation, collective-risk social dilemma, public good, community energy, environmental behaviour, impulsivity, punishment sensitivity, collective purchasing

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Correspondence:
Anya Skatova
anya.skatova@gmail.com

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INTRODUCTION

Many environmental choices represent social dilemmas (Irwin and Berigan, 2013), whether they are large-scale decisions about climate change mitigation (Milinski et al., 2008) or everyday choices such as recycling (Lyas et al., 2004) and responsible energy use at home (Leygue et al., 2014). Social dilemmas are scenarios when the communal resources have to be maintained and individuals face a dilemma between either using more than others, while sharing the costs of usage equally – thus, free-riding; or using a fair-share that allows maintaining the consumption of a resource but often with smaller immediate personal benefits. A type of social dilemma – a collective-risk game – is relevant to various social scenarios with repeated interactions and previously has been studied in the context of climate change mitigation (e.g., Milinski et al., 2008). Understanding how people act in dilemmas, such as climate change mitigation, is of high importance. However, realization of policy makers' decisions relies as much on small everyday choices of regular people as on large-scale choices about climate change mitigation by the leaders of policy making. Currently, there is not enough understanding of what people will do given various policy scenarios. We introduce a novel "in-the-wild" design of a social dilemma experiment. It takes an experimental laboratory game to everyday environments while still keeping the structure of the experimental social dilemma game. Through revealing people's behavioral strategies in the situations that resemble real-world scenarios while keeping experimental control, this approach can serve as an alternative or a precursor to expensive field studies helping to understand barriers and enablers of behavior change in the domain of energy use as well as other domains of behavior.

Community Energy Purchase Schemes

Cooperation around environmental resources is vital. For example, to achieve an 80% reduction of carbon emissions target by 2050, UK energy end-users – households, businesses, and third sector – are expected to use energy more efficiently, which among other measures includes better management of supply and demand. The benefits of encouraging communities to engage in managing their energy consumption is outlined in UK government's first Community Energy Strategy (DECC, 2014), which presents a range of initiatives that are to be supported going forward. One of these initiatives is *collective purchasing*, which "can make things cheaper, as buying in larger volumes usually means better deals and lower prices" (www.gov.uk/government/policies). Although examples are few and far between, the personal financial benefits to those who participate in collective purchasing have been demonstrated (Conaty and Mayo, 2012): for example, in the UK, an average saving of £131 was realized by households on the Cheaper Energy Together scheme [DECC, 2013; for similar evidence from Belgium, see Erbmann et al. (2009)]. Importantly, collective purchasing initiatives could also help to achieve carbon emissions targets by increasing engagement of community members in energy issues, and by reducing a variety of related emissions (e.g., the reduction in emissions related to the delivery of fuel, DECC, 2014, p. 6).

However, community energy purchase schemes can introduce interdependence of individual decisions, and so participating households might face a scenario alike a standard social dilemma. This is not accounted for in the policy documents, which focus on the positive outputs of a community purchasing initiative. Researchers have shown that near-future changes in energy infrastructure, e.g., forthcoming smart meter rollouts in the UK, will make it easier to identify which consumers might benefit by forming collectives (Vinyals et al., 2012) and what the tools might look like that help collectives deal with energy retailers (Ramchurn et al., 2013). However, in reality communities can be transient and marginalizing (Harvey and Braun, 1999), particularly to those not predicated toward collective action (Hoffman and High-Pippert, 2010), and reactions to energy initiatives by different communities will not necessarily remain positive (Walker et al., 2010).

If one of the households in the community, despite an agreement, uses unreasonably high amounts of energy and if there is no opportunities to punish the free-rider (Fehr and Gachter, 2002), will the rest of the community compensate for them by using less? Or will they retaliate and use more themselves, causing a rebound effect (Greening et al., 2000), thus eliminating the benefits of the deal secured by the community? Furthermore, if some households use a fair-share amount, will others follow an establishing norm of cooperation in the group? The present study used a collective-risk game, a type of experimental social dilemma, to model a communal energy purchase scenario "in the wild." We investigated participants' responses to free-riding or fair-share use in their group as they were going about their everyday lives, as well as what consequences the dynamic interactions over communal resources had on cooperation around energy use.

Social Dilemmas to Explain Environmental Decisions

While standard social dilemmas are conceptually applicable to many real-world scenarios, the predominant body of research in the area uses stripped down storylines where participants make decisions about money units (MUs, e.g., Fehr and Gachter, 2002). Building on previous research (Milinski et al., 2008; Jacquet et al., 2013; Leygue et al., 2014), we transformed a laboratory game to investigate whether previous experimental findings apply to more realistic, ecologically valid real-world choices. Such an approach can build a basis for establishing the constraints of current policy strategies on behaviors in schemes such as community energy purchase deals. We improved the design of the laboratory game by introducing a novel "in the wild" aspect, which aimed to enhance the ecological validity of the experiment where the decisions were made on a timeline that is closer to real-world scenarios, as well as in the familiar environment of participants' everyday life.

A collective-risk game is a scenario where a group of players interact over a course of several rounds. They are given individual endowments and have to accumulate (or save, depending on the framing) a certain amount of money in the public pot over the course of the game. If by the end of the game they do not collect enough money (or if they overspend), they are all fined equally. We applied a collective-risk game approach to study household energy decisions by simulating everyday choices in a controlled experimental design. Will a group of households participating in a community energy purchase scheme with a pre-defined limit of energy allowance manage to stay below the threshold, given the benefits of individual use? To study this question, we modified a previously reported design (Milinski et al., 2008) to fit a community energy-buying storyline. In our experiment, if the group went over the threshold, the fine occurred with 100% probability. The fine was distributed among group members regardless of their usage from the communal resource, which is similar to previous research using experimental public goods games (e.g., Croson, 2007). Such a scenario simulates more realistically the case of community energy purchase as, unlike climate change that can happen with a particular probability, energy use in real life can be measured objectively, so its over-usage would be fined with 100% certainty.

In previously reported collective-risk games, participants interacted over a number of turns with the aim to reach a collective target of contributions (Milinski et al., 2008; Santos and Pacheco, 2011; Jacquet et al., 2013). Such give-some scenarios model social decision-making in situations such as climate change mitigation (e.g., everybody needs to contribute enough to prevent a catastrophe of climate change). However, there are many real-world scenarios in for example, community buying schemes or household energy use, which could be better represented by take-some games (Leygue et al., 2014). In these scenarios, a community has to maintain the use of a communal resource under a certain threshold to avoid negative consequences, such as exhausting the resource (Van Dijk et al., 2003) or paying a fine for over-usage.

Importantly, similar to many real-life situations, in the collective-risk game participants receive frequent feedback about the behavior of others in the group throughout the game; however, the outcome for the whole game was only evident in the end. This introduced a dilemma to each individual group member. If the target was not met, the whole group suffered: every individual had to contribute equally to the fine. However, by using more individually, participants received greater private benefit. This could be especially tempting in the short-term given the structure of the game: participants were rewarded through individual usage on each turn, but rewards for cooperation or punishment for not meeting the target were distant and were revealed only in the end of the game. Such a set up gives an opportunity to study how participants react to the behavior of others and adjust their game strategy if necessary in order to reach the target. While achieving the collective target implies some individual sacrifice, it brings benefits to everybody in the group. However, there is always uncertainty for the individual about whether others in the group choose to cooperate or to free ride. Furthermore, collective-risk games allow the study of strategies that are dependent on the behavior of others. For example, one can compensate for free-riding of others (Milinski et al., 2008). Alternatively, one can also be opportunistic and expect others to compensate. Thus, the key feature of this experimental design is to observe how the behavior of others can affect people's choices in the game.

The behavior of others often serves as a cue eliciting certain norms of interaction, which people then can choose to follow (Biel and Thøgersen, 2007), and this is applicable to social dilemmas (Weber and Murnighan, 2008). However, do people always follow the example of the majority? Research on social norms, including energy use domain, suggests that the majority comply with normative usage after seeing the information about others' behavior (Schultz et al., 2007). Feedback about behavior of others is referred to as a descriptive norm of behavior, which in addition to injunctive norms (rules or standards of behavior), is suggested to affect people's choices. However, the feedback about behavior of others does not always affect decisions in a positive way, especially in the household energy use domain (Leygue et al., 2014). Field studies on household energy use also report "rebound" effects: if people find out that others use more than them, in some circumstances they can increase but not decrease their use (Schultz et al., 2007). One potential explanation for this rebound effect relates to scenarios perceived as social dilemmas where high usage by others could be perceived as unjust. In this case, instead of following the majority and using a fair-share, individuals could increase their usage in retaliation toward free-riders.

Strategies to Deal with Unfair Behavior of Others

Fairness is an important principle of human interactions. It is pervasive throughout human society: we often expect others to behave in a way that is fair to us and others (Binmore, 2014). Strong reciprocity theory suggests that violation of the fairness principle evokes strong negative emotional and behavioral reactions such as altruistic punishment of free-riders (Fehr and Gachter, 2002). Ultimatum game (UG) experiments are specifically designed to study people's reactions to fair or unfair behavior of others. One out of two players is required to divide a pot of money in two parts and the other needs to approve the outcome for both of them to receive the allocation. Around half of participants in UGs refuse the offer, which they consider unfair, even though in this case both parties get nothing (Nowak et al., 2000), which is a way to retaliate in response to free-riding. Leygue et al. (2014) found that when faced with a hypothetical scenario in which one house member overused energy and everybody has to share the bill for their overuse, participants report heightened anger. But would they retaliate and increase their energy use, as strong reciprocity theory suggests? Many social dilemmas in the real world differ from one-shot UGs as we often interact with the same individuals over a number of occasions. Retaliation in such circumstances can have negative effects on the outcome of interactions, especially if there is no opportunity to directly punish free-riders: often retaliation causes complete elimination of cooperation (Fehr and Fischbacher, 2003). This is a highly undesirable outcome for various real-life situations, including community energy purchasing scenarios. Luckily, there are other strategies to deal with free-riding that are also at play in social dilemmas (Axelrod and Hamilton, 1981; Fudenberg et al., 2012).

The literature reports a variety of "nice" strategies in social dilemmas, which under certain circumstances lead to better payoffs for the individuals employing them. In the repeated prisoner's dilemma between one- and two-thirds of participants, depending on conditions, demonstrate lenient strategies by not retaliating to defection straightaway and forgiving strategies by attempting to restore cooperation after inflicting punishment on the free-rider (Fudenberg et al., 2012). Furthermore, in a repeated social dilemma experiment, participants who consistently contribute a high amount to the communal account influence others through establishing a norm of cooperation in the group at no cost to themselves and often with some gain, which subsequently leads to increase in cooperation levels in those groups (Weber and Murnighan, 2008).

Previous research on collective-risk dilemmas has not looked into strategies in response to fair or unfair behavior of others, as well as whether normative behavior presented as feedback about decisions of others influences individual choices. However, Milinski et al. (2008) demonstrated that if the punishment was highly probable, more participants showed altruistic or compensating strategies, while if the punishment was expected with a low probability, a higher proportion of participants were opportunistic or free rode. This is relevant because similar to high versus low probability of punishment, unfair versus fair behavior of others throughout the game in the collective-risk dilemma, respectively, could be perceived by an individual as a higher versus lower chance of having to pay a fine in the end.

We predicted that in the community energy purchase game when others are using a fair-share [similar to Milinski et al. (2008) uncertain punishment condition], participants would realize that the fine is not likely to occur, so they could increase their usage, thus demonstrating opportunistic strategies. An alternative reaction to fair-share behavior of others would be adherence to the social norm of behavior (Biel and Thøgersen, 2007; Schultz et al., 2007) and usage of a fair-share amount.

When others are unfair, in the absence of opportunity to directly punish free-riders, two reactions are possible. First, in accord with retaliation literature, participants in the community energy purchase game could employ an emotionally driven retaliation strategy to punish free-riders or increase their usage. However, this behavior is highly undesirable from the rational point of view as it increases the risk of not meeting the target and, thus, might lead to punishment in the form of a fine for everybody. Thus, similar to Milinski et al. (2008) in certain punishment conditions, participants could use an alternative strategy and decrease their usage or compensate if others were unfair.

Individual Differences in Social Dilemma

While describing behavioral strategies in scenarios that resemble real-world situations – such as communal energy use – can help to explain and predict cooperative and non-cooperative outcomes for the group, it is equally important to understand the individual motivations behind people's decisions. Overall, research shows heterogeneity of behavioral strategies in various types of social dilemmas (e.g., Burlando and Guala, 2005; Zhao and Smillie, 2014); however, this heterogeneity has not been yet explored in the real-world social dilemmas, such as communal energy use. To identify potential mechanisms, we review literature on individual differences in behavior in lab-based social dilemmas.

The heterogeneity in decisions in social dilemmas has been linked to a number of psychological factors, such as personality dispositions, which reflect individual differences in processing rewards and punishments (Scheres and Sanfey, 2006; Skatova and Ferguson, 2011, 2013). Dispositional reward and punishment sensitivities are key to explain individual behavior in domains where reward and punishment processing have been strongly implicated, such as prosociality and cooperation (Gintis et al., 2003; Gneezy and Fessler, 2012; Van Lange et al., 2014; Zhao and Smillie, 2014). A psychological measure that has often been used to assess individual differences in reward and punishment sensitivity includes behavioral approach system (BAS) and behavioral inhibition system (BIS) scales (Carver and White, 1994).

The BAS scale includes three subscales: two subscales measure reward reactivity aspects of reward sensitivity [BAS-reward responsiveness (BAS-RR) and BAS-drive (BAS-D)], and one measures the impulsivity aspect of reward sensitivity [BAS-Fun Seeking (BAS-FS)]. Impulsivity is associated with the tendency to engage in behaviors which are risky and often require disinhibition, while reward reactivity refers to propensity to be sensitive to opportunities for rewards and rewarding experiences (see Smillie et al., 2006, for discussion of the distinction between reward reactivity and impulsivity). These scales were previously used to explain behavior in the economic games (Scheres and Sanfey, 2006; Skatova and Ferguson, 2011, 2013) and, thus, should be applicable for explaining behavior in a collective-risk game scenario structured around communal energy use. Specifically, participants who self-reported high sensitivity to rewarding experiences (success, social interactions, etc.) in everyday life also demonstrated more strategic behavior in social dilemmas. Skatova and Ferguson (2011) showed that high BAS-RR was associated with lower contributions in a one-shot public goods game after revealing that others in the group contributed a high amount. Scheres and Sanfey (2006) found associations of BAS-RR and BAS-D with lower offers in the Dictator Game (which is similar to the UG except that the respondent does not have an opportunity to reject the offer) but not in the UG. Pothos et al. (2011) showed that participants high in BAS-RR were more likely to defect in the one-shot prisoner's dilemma game. In all cases, participants high in reward reactivity, made a decision to defect while having full control of the situation and no dependency on the decision of other people. Therefore, their decision to defect could be interpreted as strategic and reflect the ability to better learn from reward, which they were getting in this case by defecting.

Previous studies that looked into associations between BAS scales and behavior in one-shot economic games did not find relationships between BAS-FS and individual choices. The BAS-FS scale has strongest conceptual and empirical links with impulsivity and diminished delayed reward gratification (Smillie et al., 2006; Giovanelli et al., 2013). Individual differences in behavior might be associated with differences in reward discounting when each turn of the game introduces a conflict between short-term private benefit and long-term reward by cooperation. Jacquet et al. (2013) demonstrated that discounting mechanisms affected people's decisions in a social dilemma: a greater delay in achieving rewards by cooperation made it less likely for people to cooperate in the short term in a collective-risk dilemma. Specifically, when individuals received benefits from cooperation the day after they played the game, 7 out 10 groups succeeded in reaching a cooperation target. However, when the benefits from cooperation were delayed by 7 weeks, only 4 groups out of 11 succeeded. They also demonstrated variability in individual responses: some groups were able to reach cooperation even when the benefits were delayed by 7 weeks. Previous research using public goods games found a negative association between cooperation and impulsivity but only when the reward from free-riding was tangible (Myrseth et al., 2015). It is plausible that in a game with a longer time span, where it is easier to free ride at a given turn and get away with it, BAS-FS would be associated with more selfish behaviors. That should happen especially when the risk of loss is low, as for impulsive individuals it would be easier to disregard long-term benefits of cooperation. Instead, BAS-RR and BAS-D should be positively associated with strategic behavior, leading to high certain profits in any case.

Differences in decisions in social dilemmas were associated with low self-reported sensitivity to negative experiences in real life (e.g., social disapproval, failure, etc.) measured by the BIS scale: participants with low BIS made smaller contributions in a one-shot social dilemma while facing the risk of punishment (Skatova and Ferguson, 2013). Low BIS was also associated with higher proportion of contributing nothing in a one-shot social dilemma after finding out that others contributed a high amount to the public good (Skatova and Ferguson, 2011). Finally, research suggested that interaction between BIS and BAS traits, or broadly speaking reward and punishment sensitivity systems, is associated with various clinical and behavioral outcomes, including prosocial and antisocial behavior. Specifically, McCabe et al. (2001) demonstrated that cooperation occurs through a neural network, which provides binding joint attention to mutual gains with inhibition of immediate reward: those who cooperate inhibit the dominant response of getting a quick smaller reward in order to gain a larger delayed reward by the means of cooperation.

We predicted that in the situation when others were fair and used a small amount throughout, making the risk of group punishment for overuse low, those who were higher in BAS-FS should take advantage and use more energy to get more private immediate benefits. We predicted that if others were unfair (by using high amounts throughout the game) and the risk of a fine was high, more strategically driven participants (e.g., high in BAS-RR and BAS-D) should use less to avoid paying the fine. In terms of BIS, we predicted that those who were less sensitive to the risk of punishment (e.g., low in BIS) should use more energy when the punishment was uncertain, i.e., in the fair condition. Finally, we predicted that participants high in impulsivity (measured by BAS-FS) and low in punishment sensitivity (measured by BIS) would be more likely to demonstrate opportunistic strategies when the advantage of immediate benefits were high (e.g., in the fair feedback condition).

The Present Study

Our study extended previous research to reveal whether the fair (using the pre-agreed amount of energy) or unfair (using more energy than was pre-agreed) behavior of others influenced individual decisions over the course of a collective-risk social dilemma. Specifically, we employed an experimental game to model household energy use in the context of a community energy deal, where individuals were part of a group of households that collectively pre-paid for a certain amount of energy to use per week. If the group overused energy, a fine was distributed between all group members equally.

We manipulated feedback about the behavior of others as fair or unfair, and investigated how such feedback influenced participants' individual decisions about energy usage in their own households, resulting in a variety of strategies: fair-share (to use as much as established by social convention), opportunistic (use more to gain private benefit even at a risk of a group-level fine), retaliatory (increase the usage after facing unfair behavior of others), or compensatory (decrease the usage in order to compensate for high use of others and so avoid the fine). We further looked at whether the different strategies were associated with individual differences in punishment (measured by BIS) and two distinct aspects of reward sensitivity: reward responsiveness (measured by BAS-RR and BAS-D) and impulsivity (measured by BAS-FS).

Our participants made decisions through a smart-phone or a home PC while going about their everyday lives as opposed to interacting with other group members in laboratory settings. In addition, unlike in laboratory settings, where participants usually make decisions every minute, our participants replied just once a day in the morning, wherever they were at the moment, and by using their mobile phone or computer at home. This is an important feature of the study as it aimed to reveal potential conflict between short-term and long-term benefits: participants were rewarded for their energy use every day, while the bill revealing potential excess would arrive only in the end of the (actual) week. Such features of the game provided a more accurate simulation of real-world decisions. The data presented in this paper are a subset of data collected within the project. Here, we focus on details of the design that are relevant to the aims presented in this paper.

MATERIALS AND METHODS

Participants and Procedure

The study was conducted through Qualtrics software. Overall, 118 UK-based participants volunteered to participate (74 females; age: range 25–66, $M = 35$; 46 were homeowners). Out of 118, 78 participants partook in fair and unfair condition, $N = 39$ for each condition. For all analyses below, we used only data from these 78 participants (see Design for further explanation why only fair and unfair conditions were focus of analyses in this paper).

We aimed to recruit participants who were responsible for paying their own bills as for them the decisions in the game would have greater resemblance to real life. For that reason, we explicitly sought to recruit a non-undergraduate sample of participants. In the UK, students often have their energy bills included as a part of a rental contract. In these circumstances, there is no monetary incentive to use energy responsibly (as they pay the same amount in any case). Participants were recruited in two cities in the Midlands, UK via various university-wide mailing lists and a list of members of an energy trial conducted by a national energy company.

All participants were briefed and debriefed in person. At the briefing, they received full instructions and could try out the game. They also filled in demographic information and a BIS/BAS questionnaire. We used the BIS/BAS questionnaire (Carver and White, 1994) to measure differences in reward and punishment sensitivities. Participants rated various statements on a 4-point

TABLE 1 | Person zero-order correlations for BIS and BAS subscales.

	BIS	BAS-D	BAS-FS
BIS	–		
BAS-D	–0.02	–	
BAS-FS	–0.13	0.44***	–
BAS-RR	0.43***	0.37**	0.17

****p < 0.001, **p < 0.01.*

scale ranging from "very true for me" to "very false for me." BIS/BAS questionnaire was scored as four scales: BIS scale ($M = 3.02$, SD = 0.52, α = 0.77, seven items, example item: "Criticism or scolding hurts me quite a bit") and three BAS scales: BAS-D ($M = 2.67$, SD = 0.60, α = 0.74, four items, example item: "I go out of my way to get things I want"), BAS-FS ($M = 2.81$, SD = 0.58, α = 0.72, four items, example item: "I often act on the spur of the moment"), and BAS-RR ($M = 3.38$, SD = 0.47, α = 0.73, five items, example item: "When I'm doing well at something I love to keep at it"). **Table 1** reports zero-order correlations between BIS and BAS subscales. For the presentation of results, BIS/BAS scores were reversed; so high rating represents high ends of the BAS and the BIS scales. There were no differences on any of BIS/BAS scales between conditions. All scales were *z*-scored for all analyses.

All participants who completed the study were compensated £40 (~$61) for their time. In addition, they were incentivized by being paid contingent on their choices in the experiment (see The Game). In the end, participants were paid additional £3 (~$5) on average based on their responses. The study was approved by the School of Computer Science Ethics Committee at The University of Nottingham.

Design

Participants were divided into three conditions: fair, unfair, and real. Each condition included 4 groups of 10. As only 118 participants were recruited, two participants were lacking to form 12 full groups of 10. However, for fair and unfair conditions, it did not matter if there was not a full group of 10 as the feedback about group behavior was pre-set. Therefore, we assigned 39 participants for each of manipulated conditions. Thus, we manipulated the feedback about the behavior of others in 8 out of 12 groups in a between-subjects design as fair versus unfair usage. During the game, participants in the "fair" condition received feedback, which indicated that others in their group consumed energy within the pre-agreed norm, i.e., the group's deal allocation. The feedback was generated to represent a plausible distribution with a mean of 3.7 energy units (EUs) and SD of 0.48 EUs. The mean and SD was estimated based on the pilot study data. In the "unfair" condition, feedback indicated that their group partners consumed more than was pre-agreed (simulated in the similar way to fair condition, $M = 4.4$ EUs, SD = 0.47 EUs). The exact feedback on each day for each condition can be found in the Supplementary Materials. In the "real" condition, participants received accurate feedback about the consumption of others in their group ($M = 3.87$ EUs, SD = 0.90 EUs). To avoid deception, it was explained to participants prior to the study that some groups would receive manipulated feedback but neither experimenter nor they would know which group they were assigned to (Bardsley, 2000). As the purpose of this paper was to investigate the effect of fair and unfair behavior of others on individual strategies in a collective-risk dilemma, here we only report the results for fair and unfair conditions.

The Game

The Village Energy Deal

Participants had to imagine that they and nine other households in their virtual village were participating in a deal to purchase energy communally. The deal lasted for a week and provided a pre-paid energy amount for the village (the group of 10 households), i.e., 280 EUs shared across the whole group. Each participant received a 62-MU endowment, of which they were deducted 28 MUs for inclusion in the pre-paid deal, leaving a remainder of 34 MUs in their private account. This remainder could be spent on excess energy use (in response to hypothetical situations encountered in the game, as described later), or saved to be converted into pounds in the end of the experiment at a rate of 1 MU = £0.02. Excess energy use, i.e., any energy used over the village's 280 EU allowance, was twice as expensive as energy paid for through the village's deal, costing 2 MUs per 1 EU. The cost of any excess energy that was used had to be paid for communally, divided equally between all group members.

Using Energy

The only way participants used energy during the game was by setting heating in their individual virtual households. The heating was set in heat points (HPs) that reflected a subjective energy scale from very cool (1 HP) to very warm (6 HPs). HPs were introduced (as opposed to degrees Celsius or Fahrenheit) as people have different subjective perceptions of what warm or cold feels like. For example, for somebody 18°C at home might seem as quite "warm," while for somebody else it might seem as "cold" (Li, 2005). The use of 1 HP resulted in expenditure of 1 EU.

Participants received private incentives to heat their homes: 1 HP used added 0.25 MUs to their private account. That meant the more energy they used, the more monetary benefits they would receive after the end of the game. Participants were told that all households in the group were similar in the level of energy efficiency and how much energy they used regularly.

As a result, if all participants kept their use to the norm, as suggested by the rules of the village's energy deal (i.e., up to 4 HPs per day, for 7 days), the group would not consume excess energy and not have to pay extra at the end of the week. If the group overused, all participants had to share a fine (i.e., pay for the excess), regardless of their individual use. Therefore, the scenario represented a social dilemma, where private interest (to use as much as possible in order to gain a monetary incentive) clashed with public concern (to keep the use down in order to avoid a collective fine).

Playing the Game

Participants were instructed that one round of the game lasted a week, with seven turns. One turn took place each day of the week. In the morning of each day of the study, participants received a text message or an email with a link that they had to follow to engage in the game. The link provided the following information:

- A recap of the previous day, including the average energy consumption of other members of the village; a reminder of how much they used themselves; how many MUs they received as a benefit from previous day's use;
- A summary of the week so far, including how much the village had consumed, how much was left in the community deal allocation for the week, and how many days were left in the week.

Following this feedback, participants had to make one decision about temperature in their virtual house for this day. This consisted of choosing a temperature setting from a scale ranging from very cool (1 HP) to very warm (6 HP).

Participants were also provided with a background story to make their hypothetical day-to-day decisions feel more real. Prior to the study, we asked participants to name three close real-life friends and/or family members who might come to visit them at Christmas. We used these names to individualize the reminders sent to participants during the game, telling participants that it was Christmas time and that those friends and/or family members had come to stay with them. Their additional goal in the game was then to make their guests happy by keeping the house warm, while also attempting to save the money in their private account by avoiding the costs incurred by the group exceeding their deal's communal allowance.

On the eighth day of the game, participants received information about energy consumption for the preceding week, learnt whether the group had exceeded its deal's allocation and, thus, whether they needed to contribute a payment towards the fine, if there was a fine, and how much they had to pay. In addition to the decisions about energy use in their virtual house, we also measured a number of psychological variables before and after participants set the temperature every day. As these variables were not the focus of this paper, we are omitting them from any further analyses or discussion. After the first week of the study, participants participated in an extension of the game with the same group partners. Only results from the first week are reported in this paper. A complete design of the project is available from the first author. At the end of the study, participants were rewarded based on the MUs remaining in their private accounts plus the participation fee.

RESULTS

Response Rate

Participants responded on 6.4 days on average and there was no difference in response rate between conditions: $t(68.77) = -0.62$, $p = 0.54$. The rules of the game stated that if participants missed a response on a particular day, the temperature they set for the previous day would be carried over. We excluded from analyses participants' data when they missed more than one response during the week. Eighty-five percent ($N = 66$) of participants responded on at least 6 days of the study. Only these responses were used for all further analyses. Whenever we presented aggregated responses from a specific day of the study, we also excluded participants who did not provide responses on that specific day from all relevant analyses. Response rate for each day of the study for those who responded on at least 6 days for the study was the following: 98% ($N = 65$) participants provided responses responded on day 1, 97% ($N = 64$) on day 2, 98% ($N = 65$) on day 3, 100% ($N = 66$) on day 4, day 5, and day 6, and 74% ($N = 49$) provided responses on day 7. The lower response rate on day 7 can be explained by failure of experimental software on that day. On that specific day, the reminder that went out to participants contained a link with incorrect feedback information. Most participants responded to this incorrect reminder, but we had to disregard those responses. Later in the same day, participants received a correct link with a request to respond again, however, not everybody responded to this second reminder. The response rate to the second reminder on day 7 was similar across conditions: 24 participants responded in the fair and 25 in the unfair condition. We further checked that all our results remained the same if we ran analyses on a restricted sample of those who responded on day 7 (results are presented in **Tables 3** and **4**).

Average Use Compared to the Fair-Share

Mean use across the week was 3.5 HPs (SD = 0.88) (see **Table 2** for means and SDs of energy use per day, overall and per condition and **Figure 1** for graphical representation). Individual use fell in the range of all possible options: participants used from 1 to 6 HPs, with 51% of all responses falling on the choice of 4 HPs, 31%, 3 HPs; 9%, 2 HPs; 3%, 1 HPs; 4%, 5 HPs; and 2%, 6 HPs. As 4 HPs seemed to be a common option for many (which is not surprising as it was suggested as a normative expenditure in the

TABLE 2 | Means and SDs of energy use for each day of the week for the whole sample, fair and unfair condition.

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Overall	Mean	3.51	3.41	3.43	3.39	3.61	3.59	3.55
	SD	0.79	0.77	0.85	0.89	0.94	0.91	1.02
	N	65	64	65	66	66	66	49
Fair condition	Mean	3.42	3.37	3.48	3.48	3.81	3.73	4.12
	SD	0.79	0.83	0.91	1.03	0.92	0.94	0.99
	N	33	32	33	33	33	33	24
Unfair condition	Mean	3.59	3.44	3.37	3.30	3.39	3.45	3
	SD	0.80	0.72	0.79	0.73	0.93	0.87	0.71
	N	32	32	32	33	33	33	25

N represents number of participants responded on each day.

TABLE 3 | Model 1: mixed-effects random intercept regression model predicting the usage on day$_i$.

	Full sample (N = 65)		Restricted sample (N = 48)	
	Fixed effects			
	B (SE)	**95% CIs**	**B (SE)**	**95% CIs**
Intercept	3.66*** (0.09)	3.49; 3.85	3.70*** (0.12)	3.46; 3.94
Usage on Day 1	0.38*** (0.05)	0.27; 0.49	0.40*** (0.06)	0.27; 0.52
Day number	0.03 (0.02)	−0.003; 0.06	0.04 (0.02)	−0.001; 0.07
Condition (0 – fair, 1 – unfair)	−0.32** (0.11)	−0.54; −0.10	−0.39** (0.14)	−0.67; −0.12
Day number × Condition	−0.15*** (0.03)	−0.21; −0.09	−0.18*** (0.04)	−0.25; −0.11
	Random effects			
Intercept σ (participant)	0.38		0.42	
Observations	435		333	

Terms of all interactions were centered to reduce multicollinearity. The table reports unstandardized estimates with SEs in parenthesis and 95% confidence intervals for full (N = 65) and restricted (N = 48) sample.
****p < 0.001, **p < 0.01.*

TABLE 4 | Model 2: mixed-effects random intercept regression model predicting the usage on day$_i$.

	Full sample (N = 65)		Restricted sample (N = 48)		Simulations (n = 10,000)
	Fixed effects				
	B (SE)	**95% CIs**	**B (SE)**	**95% CIs**	**1 – β[a]**
Intercept	3.75*** (0.13)	3.53; 3.98	3.82*** (0.16)	3.55; 4.07	1
Use on Day 1	0.42*** (0.07)	0.29; 0.54	0.45*** (0.09)	0.31; 0.60	1
Day number	0.01 (0.02)	−0.02; 0.05	0.01 (0.02)	−0.03; 0.05	0.12
Condition (0 – fair, 1 – unfair)	−0.33* (0.15)	−0.58; −0.07	−0.37* (0.18)	−0.67; −0.08	0.87
Day number × Condition	−0.14*** (0.04)	−0.21; −0.07	−0.14*** (0.04)	−0.21; −0.06	0.98
BAS-RR	0.03 (0.09)	−0.12; 0.18	0.03 (0.11)	−0.15; 0.20	0.07
BAS-RR × Day number	0.02 (0.02)	−0.02; 0.06	0.03 (0.02)	−0.01; 0.07	0.17
BAS-RR × Condition	−0.003 (0.17)	−0.30; 0.29	−0.04 (0.22)	−0.39; 0.30	0.05
BAS-RR × Day number × Condition	−0.01 (0.04)	−0.10; 0.07	−0.01 (0.05)	−0.10; 0.08	0.06
BAS-D	−0.05 (0.09)	−0.21; 0.10	−0.05 (0.12)	−0.24; 0.14	0.12
BAS-D × Day number	−0.04 (0.02)	−0.08; −0.00001	−0.03 (0.20)	−0.08; 0.01	0.48
BAS-D × Condition	0.05 (0.18)	−0.25; 0.35	0.07 (0.22)	−0.29; 0.42	0.07
BAS-D × Day number × Condition	0.07 (0.04)	−0.02; 0.15	0.03 (0.05)	−0.06; 0.12	0.32
BAS-FS	0.05 (0.09)	−0.11; 0.21	0.15 (0.14)	−0.08; 0.37	0.12
BAS-FS × Day number	0.08** (0.02)	0.03; 0.13	0.09** (0.03)	0.03; 0.15	0.95
BAS-FS × Condition	−0.32 (0.18)	−0.64; −0.002	−0.46 (0.28)	−0.92; −0.003	0.66
BAS-FS × Day number × Condition	−0.12* (0.05)	−0.22; −0.03	−0.14* (0.06)	−0.26; −0.03	0.81
BIS	−0.07 (0.08)	−0.20; 0.06	−0.10 (0.10)	−0.26; 0.06	0.19
BIS × Day number	−0.08*** (0.02)	−0.11; −0.04	−0.08*** (0.02)	−0.12; −0.04	0.95
BIS × Condition	0.10 (0.16)	−0.17; 0.38	0.14 (0.20)	−0.20; 0.47	0.14
BIS × Day number × Condition	0.13*** (0.04)	0.06; 0.20	0.13** (0.04)	0.05; 0.21	0.88
BIS × BAS-RR	−0.01 (0.09)	−0.17; 0.15	−0.03 (0.12)	−0.22; 0.17	0.06
BIS × BAS-RR × Day number	0.05 (0.02)	0.001; 0.09	0.04 (0.03)	−0.01; 0.09	0.45
BIS × BAS-RR × Condition	−0.01 (0.19)	−0.33; 0.31	0.10 (0.24)	−0.29; 0.48	0.05
BIS × BAS-RR × Day number × Condition	−0.03 (0.05)	−0.13; 0.06	−0.04 (0.05)	−0.15; 0.05	0.10
BIS × BAS-D	0.02 (0.09)	−0.13; 0.18	0.02 (0.12)	−0.16; 0.21	0.06
BIS × BAS-D × Day number	0.01 (0.02)	−0.03; 0.05	0.001 (0.03)	−0.05; 0.05	0.07
BIS × BAS-D × Condition	−0.11 (0.18)	−0.43; 0.20	−0.24 (0.24)	−0.63; 0.15	0.10
BIS × BAS-D × Day number × Condition	−0.10* (0.05)	−0.18; −0.01	−0.10 (0.05)	−0.20; 0.00003	0.45
BIS × BAS-FS	−0.12 (0.10)	−0.29; 0.05	−0.21 (0.15)	−0.45; 0.04	0.34
BIS × BAS-FS × Day number	−0.04 (0.03)	−0.09; 0.01	−0.04 (0.03)	−0.10; 0.02	0.38
BIS × BAS-FS × Condition	0.20 (0.20)	−0.14; 0.55	0.48 (0.31)	−0.02; 0.98	0.25
BIS × BAS-FS × Day number × Condition	0.15** (0.05)	0.06; 0.25	0.21** (0.07)	0.08; 0.34	0.82
	Random effects				
Intercept σ (participant)	0.42		0.48		–
Observations	435		333		–

Terms of all interactions were centered to reduce multicollinearity.
The table reports unstandardized estimates with SEs in parenthesis and 95% confidence intervals for full (N = 65) and restricted (N = 48) sample. Simulation results represent power calculation for each fixed effect at 0.05-level using 100 random samples and 100 simulations per each sample.
****p < 0.001, **p < 0.01, [a]α = 0.05.*

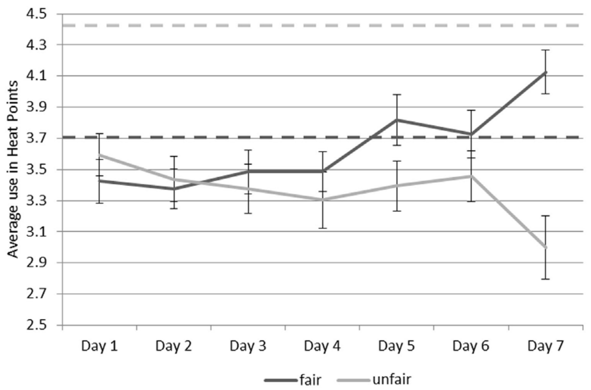

FIGURE 1 | Average use of energy on each day of the week in fair and unfair condition. Error bars represent SE of the mean. Dotted lines show manipulated groups' average (fair versus unfair).

instructions), first we investigated whether the average behavior in the game deviated from a fair-share usage (i.e., a choice of 4 HPs), and whether there were any differences between conditions in this respect. On average, participants in the fair condition used 3.61 HPs during the week (SD = 0.62), while participants in unfair condition used 3.38 HPs (SD = 0.58). Both values were significantly lower than the suggested "norm" of 4 HPs: one-sample t-test comparing a mean usage in each condition to 4: t (32) = 33.48, p = 2.2e−16 for fair condition, and t (32) = 33.41, p = 2.2e−16 for unfair condition. This suggests that most people did not overuse energy to make private profits – they used a fair-share or up to 4 HPs – even though using as much as possible (up to 6 HPs) would be rational due to the structure of the game.

Differences in Use in the Fair Versus Unfair Condition

Furthermore, we investigated the use for the week day-by-day for fair and unfair conditions separately. There was no difference in day 1 use between fair (M = 3.42, SD = 0.79, SEM = 0.14) and unfair (M = 3.59, SD = 0.80, SEM = 0.14) conditions: t (62.91) = −0.86, p = 0.39. To investigate whether fair or unfair condition had an effect on individual use, we ran a mixed-effects random intercept regression model (Model 1) estimated by maximum likelihood using lme4 package in R (Bates et al., 2014) predicting energy use on each day from condition (fair, coded as "0," versus unfair, coded as "1"). The regression included random intercept for each participant to account for dependency between observations. We controlled for the use on day 1 to account for individual baseline. We also controlled for learning effects through using day number as a predictor: it is possible that participants would change their energy use across the week as they learn about the game and behavior of others. Predictors entered into all interaction terms were mean-centered to reduce multicollinearity.

The results (see **Table 3**) demonstrated that significant predictors of use were the consumption on day 1 (B = 0.38, SE = 0.05, p = 0.00001), condition (B = −0.32, SE = 0.11, p = 0.007), and interaction of the day of response by condition (B = −0.15, SE = 0.03, p = 0.00001). **Table 2** reports means and SDs per condition per day of response reflecting a steady increase of overall use across the week and differences in the pattern of use for conditions: the use in the fair condition increased toward the end, while there was relative lack of change in use by participants in the unfair condition across all days apart from drastic decrease in use on the last day before the end of the game, day 7. This suggests that there was a general trend of increase in HP use over the week, however, it was reversed for unfair condition: participants in the unfair condition decreased their use toward the end of the week. Specifically, 68% decreased their use on the last day compared to the first day, 20% did not change, and 11% increased their use in the unfair condition, while 63% increased their use on the last day compared to the first day, 20% did not change, and 18% decreased their use in the fair condition. The results remained the same for the restricted sample (see **Table 3**).

Individual Differences and Strategies in the Game

We further investigated whether individual differences in change of strategies in the games can be attributed to personality traits. We predicted energy use on each day and used the same specification for the mixed-effects random intercept regression model as Model 1 to which we added personality traits predictors and interactions of personality with other effects. Model 2 included main effects of BIS and all BAS subscales; two-way interactions between BIS and each BAS subscale; two-way interactions between each personality subscale and day number; two-way interactions between each personality subscale and condition; three-way interactions between each personality subscale, day number, and condition; three-way interactions between BIS, each BAS subscale, and day number; three-way interactions between BIS, each BAS subscale, and condition; as well as four-way interactions between BIS, each BAS subscale, day number, and condition. See **Table 4** for the full specification of the model. All predictors entered into the interaction terms were mean-centered to reduce multicollinearity. In order to assess the posterior power of the results, we ran simulations (Martin et al., 2011). First, we generated 100 samples of simulated data for all independent variables, with each variable randomly drawn from a normal distribution with a mean and SD of the respective variable from our sample (N = 65), restricted to a variable's respective actual minimal and maximum value. As personality traits (BIS, BAS-RR, BAS-FS, and BAS-D) were correlated, their simulated scores were drawn from a normal multivariate distribution which, in addition to means and SDs from the sample and low/high limits of each variable, also accounted for covariance between each variable. Second, for each of 100 samples, we simulated 100 vectors of the dependent variable (energy use on each day) by using simulated dependent variables, as well as fixed and random effects parameters from Model 2. Third, we ran regression models, as specified in **Table 4**, with 10,000 sets of simulated data: 100 samples, each simulated 100 times. Finally, we determined the power of the analysis by looking at the proportion of significant results at 0.05-level for each of the fixed effect in Model 2. The results of power analyses are reported in **Table 4**.

The results confirmed the previous analysis with energy use predicted by the consumption on day 1 ($B = 0.42$, SE = 0.07, $p = 0.00001$), condition ($B = -0.33$, SE = 0.15, $p = 0.032$), and interactions between day number and condition ($B = -0.14$, SE = 0.04, $p = 0.0002$). In addition, there was an effect of personality traits. Specifically, there was a positive effect of the interactions between BAS-FS and day number ($B = 0.08$, SE = 0.02, $p = 0.001$), a negative effect of the interactions between BIS and day number ($B = -0.08$, SE = 0.02, $p = 0.00001$), a negative effect of the three-way interactions between BAS-FS, day number, and condition ($B = -0.12$, SE = 0.05, $p = 0.011$), a positive effect of a three-way interactions of BIS, a day number, and condition ($B = 0.13$, SE = 0.04, $p = 0.0001$), and a positive effect of a four-way interactions between BIS, BAS-FS, day number, and condition ($B = 0.15$, SE = 0.05, $p = 0.0032$). All results remained significant in the restricted sample. All effects were detected with sufficient power (>80%) at significance level of 0.05. There were no effects of BAS-RR or BAS-D on behavior in the game.

To analyze the results of the interactions, we calculated mean predicted values of consumption for high- and low-end participants of each trait, using results of regression analysis, Model 2. High- and low-end participants were identified as above or below of a respective scale of the sample's average. We then calculated the change for each group of participants (e.g., high versus low BAS-FS group) between days 1 and 7 to illustrate changes in behavior during the week. Analysis of interactions suggests the following interpretation of results: BAS-FS and BIS can explain some variability in individual decisions. Specifically, those who are high in BAS-FS used more toward the end of the week overall, with a predicted average increase between days 1 and 7 of 0.42 EUs, compared to 0.04 EUs increase in those who are low in BAS-FS. Likewise, those who are low in BIS used more toward the end of the week overall, with a predicted average increase of 0.43 EUs compared to high BIS group, who had a predicted decrease of 0.04 EUs. The effects of personality traits were specific to the fair condition: only in the fair condition, participants high in BAS-FS demonstrated a predicted average increase of their use on 1.28 EUs on average between days 1 and 7 (0.33 increase for low BAS-FS participants), while low BIS participants demonstrated a predicted increase of 1.16 EUs (0.16 for high BIS participants). In the unfair condition, both low/high BAS-FS and low/high BIS participants decreased their consumption: high BAS-FS on 0.25, low BAS-FS on 0.31, high BIS on 0.27, and low BIS on 0.29 EUs. Thus, high BAS-FS and low BIS explain some variation in increased use toward the end of the week, but only in the fair condition.

Finally, the investigation of the four-way interaction of BAS-FS, BIS, condition, and day of response suggests that specifically in the fair condition those who are high in BAS-FS and at the same time low in BIS produce the largest increase in use: by 2.77 EUs difference between days 1 and 7, while high BAS-FS and high BIS produced a 0.42 EUs increase, low BAS-FS and low BIS – 0.62 EUs, with low BAS-FS and high BIS participants not changing their use in the fair condition between days 1 and 7. All participants in the unfair condition produced a decrease in use with high BIS/low BAS-FS and low BIS/high BAS-FS decreasing on 0.39 EUs, while high BAS-FS and high BIS on 0.11, low BAS-FS/low BIS on 0.22 EUs. The actual aggregated responses of the groups broken down by high/low BIS and BAS-FS, as well as by condition for each day are depicted on the **Figure 2**.

DISCUSSION

Behavior in social dilemmas often depends on what others do. After we get feedback about others, we adjust our strategy for future interactions. This paper presents the results of a community purchase energy game structured as an inverted collective-risk dilemma with seven turns before the final outcome is revealed. Participants entered decisions simultaneously with nine other players in their group using their own smart phones or computers at home over a course of a week-long game. Each day, before they made a decision, they also received aggregated information about behavior of others in the group for the previous day. In some groups, we manipulated behavior of the group as fair – the followed a pre-defined group norm of use – or unfair, where the rest of the group used more than was pre-defined.

We find that the majority of participants who were in the unfair condition demonstrated generous behavior: 68% decreased their use on the last day compared to the first day to compensate for the high use of others. This indicates that individuals in groups were good at dealing with effects of free-riding of others, especially as the punishment for group-level non-cooperation was certain. Further we find that the majority of participants in the fair condition demonstrated opportunistic behavior: 63% increased their use on the last day compared to the first day. The findings suggest that individuals did not follow either descriptive ("what others do") or injunctive ("what I am supposed to do") social norms of behavior especially under low risk of punishment for free-riding: in the fair condition participants used significantly more than their group on the last day of the study, while in the unfair condition significantly less than their group.

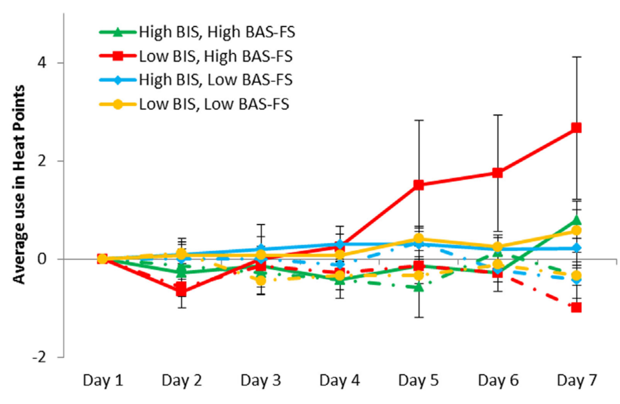

FIGURE 2 | Average use of energy on each day of the week grouped by condition (unfair versus fair) and four different combinations of low and high scores on BIS and BAS-FS: (1) high BAS-FS and high BIS; (2) high BAS-FS and low BIS; (3) low BAS-FS and high BIS; (4) low BAS-FS and low BIS. Error bars represent SE of the mean. The scores are corrected for the baseline use in the first day. High/low groups are identified based on above/below the mean of a respective scale. Dotted lines represent fair, and solid – unfair condition.

We find that individual differences in impulsivity, measured through BAS-FS, and punishment sensitivity, measured through BIS, were associated with opportunistic strategies in the fair condition. In particular, those who were high in BAS-FS and low in BIS used more on the last turn of the game showing over 2 EUs increase on the last day of the game compared to the first day. We further discuss contribution of the results of the paper to the literature on social dilemmas, individual differences, and understanding of energy behaviors.

Compensating and Opportunistic Strategies in Multi-Turn Social Dilemmas

Strong reciprocity theory suggests that if others are free-riding, people will punish free-riders even at a cost to themselves (Fehr and Gachter, 2002). Our results show that only a small proportion of individuals retaliated by increasing their use when others were unfair, with the majority being generous and compensating for others. Thus, we did not find evidence for strong reciprocity theory in our experiment. It is possible that strong reciprocity does not explain cooperation in social dilemmas that involve interactions over multiple turns. This is in line with previous research suggesting that strong reciprocity cannot always explain how people manage free-riding behaviors in social dilemmas (Yamagishi et al., 2012). In the case of our game, from an individual player perspective, the more others used, the higher was the likelihood of the fine for the group. Therefore, the reason why participants were generous can be explained by high risk of punishment. This is in line with Milinski et al. (2008) who found that in a multi-turn collective-risk dilemma in the high punishment risk condition more participants demonstrated compensating strategies toward the end of the game.

In addition to the risk of punishment, it is possible that participants were generous in this condition because of the take-some framing of the game. This is in line with previous research: it is often reported that people cooperate more in take-some dilemmas (Van Lange et al., 2013). Furthermore, the instructions could have had an influence too: participants knew that their task was not to use over the limit as a group. Such instructions could have enhanced a goal to achieve the results that were best for the group. Previous research demonstrated that goal-orientation has an effect on people's behavior in social dilemmas. Specifically, people can assign the importance on self- or other-beneficial outcomes (van Lange, 1999) and depending on the framing of the outcome, this can lead to either selfish or other-regarding behavior (Van Lange et al., 2013).

However, even though in this game the majority of participants did not retaliate, this does not mean they were indifferent to the fact that others in their group were unjust. Psychological factors, such as emotions and cognitive appraisals, are strongly implicated in the way people judge a situation that involves unfairness of others (e.g., Ketelaar and Tung Au, 2003; Sanfey et al., 2003; Nelissen et al., 2007). In our case, even if our participants felt angry, most of them did not act on their emotions as demonstrated by decrease in energy use in the unfair condition. The result also cannot be explained by opportunity to "cool down" (Dickinson and Masclet, 2015) as the decision of how much to use on a particular day had to be made straight after being presented with the feedback about others. It is still not clear what the cost of generosity was for individual participants in circumstances when others were unfair. Being angry and not having an opportunity to deal with the emotion (by either reappraising or acting on it) can have detrimental effects on one's wellbeing (Zammuner and Galli, 2005; Barrett et al., 2013) and have negative consequences for future interactions (e.g., Pillutla and Murnighan, 1996). Future research needs to investigate the role of psychological factors on behavioral strategies in multi-turn games, such as collective-risk social dilemmas with and without opportunities to impose sanctions or act on one's emotions in some way, as well as what consequences psychological factors, such as emotions, could have on people's behavior and interactions beyond an experimental game.

While in the unfair condition, participants were generous, the opposite was observed in the fair condition. In this condition, the majority of participants increased their use toward the end of the game. Contrary to social norms literature (Schultz et al., 2007), which suggests that both descriptive (do as others do, in our case implemented through feedback about behavior of others) and injunctive (do as you think is right, in our case implemented through the instruction of normative use of 4 HPs) norms guide people's behavior, in our game, participants did not follow the norm of use demonstrated by their confederates through manipulated feedback, or as it was reinforced in the instructions for the experiment. This suggests the influences of social norms on behavior might be weaker if there are other motivations guiding people's choices, such as getting individual private benefits or maximizing individual profit through avoiding a group-level fine (Charness and Rabin, 2002). However, as the reported results only cover one game, it is not clear what the participants in the unfair condition would do should they have another round of interactions with their group partners.

Participants in the fair condition significantly increased their consumption. The increase throughout the game is in line with rebound effects in energy use domain: when presented with real feedback about energy use of other households people find out that they used less than others, under some circumstances, they can increase their energy use (Leygue et al., 2014). Use of over the fair-share allowance by 30% of participants at some point in the game further indicated a different type of individual behavior in response to feedback about others – a type of weak free-riding (Keser and van Winden, 2000), which has negative consequences especially considering the environmental context of these decisions. While the findings are at odds with social norms literature, they are in line with literature on collective-risk games. Milinski et al. (2008) demonstrated that in low punishment risk condition participants free rode more. In the case of our fair condition, participants presumably also perceived risk of punishment as low; therefore, they chose to take advantage of the situation.

On the one hand, given the structure of the game, it was rational to use more when there was an opportunity, as one could get additional private benefits for usage. What is rational in the current situation could depend on the context and it is possible that our participants just aimed to optimize their profit in the game and disregarded the broader environmental picture. However, the environmental context of the game puts the decision into a different perspective, as the overarching goal of such energy purchase scheme is ultimately to decrease energy use. It is noteworthy that people still increased their energy use for private benefit, despite knowing that doing so can have consequences for the environment. While this result can be also explained by the fact that some participants might have not considered environmental framing of the game, understanding people's motivations behind free-riding is important, as it can explain why people do not make environmentally friendly choices in the real world, including not making links between their own actions and consequences for environment. For example, future energy collectives individuals might employ such opportunistic strategies by accumulating more energy than their fair-share in personal storage. Previous research suggests that people justify free-riding behavior by denying their responsibility for the outcome (Schwartz and Howard, 1982) or by convincing themselves that their behavior would not make a difference to the group outcome (Kerr and Kaufman-Gilliland, 1997). It is possible that in the case of this game, participants felt that increasing usage would not impact the outcome, so they could behave opportunistically. It is also plausible that participants behaved rationally and optimized their profits. However, whichever reason was driving the behavior of the majority, similar choices in real world have negative implications for issues such as climate change mitigation. Our findings can be used by policy makers to develop and model approaches to predict and discourage opportunistic strategies. Based on our findings, policy makers could benefit by building in an incentive structure to encourage cooperation and to prevent opportunistic behavior in future scenarios.

Individual Differences and Opportunistic Strategies

While some participants used an opportunity to get additional profits in the fair condition, about 40% did not demonstrate such behavior: they either did not change or decreased their usage. We showed that individual differences in impulsivity and punishment sensitivity were associated with opportunistic strategies. Specifically, participants with high BAS-FS and low BIS increased their energy use toward the end of the game significantly more than other participants. Results are in line with previous findings that impulsive individuals are more likely to be biased toward an immediate reward in the situations where there is a conflict between immediate and delayed reward (Smillie et al., 2006). In our study, participants knew that using more HPs would increase their profits, so they received immediate gratification from using HPs, while the reward through cooperation was delayed by at least one day (in case of the last turn decision) or more days (in case of all other decisions). This result is in line with findings of Myrseth et al. (2015) who demonstrated negative associations between impulsivity and cooperation when immediate rewards for free-riding were more salient and tangible. Furthermore, in line with predictions, we found that participants who were low in BIS were more likely to free ride when the risk of punishment was low, i.e., in the fair condition. This supports previous research, suggesting that inhibitory mechanisms are implicated in prosocial choices as one needs to withhold an initial impulse to free ride in order to get better rewards through cooperation in the future (McCabe et al., 2001; Skatova and Ferguson, 2013).

Our findings contribute to the understanding of conditions necessary in order to maintain cooperation in groups especially around environmental issues. For example, Freytag et al. (2014) found that intermediate targets featuring environmental protection as a process helped to improve cooperation in collective-risk dilemmas. It is possible that introduction of intermediate targets and rewards in a community energy purchase scenario, for example, through messages that enhance environmental consequences of various decisions or through opportunities for reputation formation could reduce opportunistic behavior in the collective-risk game among impulsive individuals with low inhibitory control.

We did not find predicted associations between other subscales of BAS (BAS-RR and BAS-D) and behavior in the experiment. In previous studies that demonstrated associations between reward responsiveness component of BAS, namely BAS-RR and BAS-D, and free-riding behavior in economic games, participants had full information about behavior of others or control over the situation while making their decision. Thus, selfish choices of reward responsive participants could have been explained by the fact that they learned better from reward and made a selfish choice to take advantage of a certain increase in profits. In our design even for the last decision, there was some uncertainty about behavior of others. This different structure of the game can explain why there were no associations of BAS-RR and BAS-D with behavior in the unfair condition. While we did not find any associations of individual differences and behavior in the unfair condition, future research could study the motivation behind generous compensating strategies in collective-risk dilemmas.

Implications for Policy Around Energy Use

Many researchers highlight that it is important to extend lab-based paradigms and develop social dilemma research designs that help to mirror important features of real-world behavior in social dilemma-like scenarios (e.g., Van Lange et al., 2013). Such research can help to identify constraints of policies and test out model scenarios in various areas of social decision-making. The results of the study presented here suggest that community energy purchase deals could backfire as we predict that under certain conditions people will increase their energy usage, especially if there is an opportunity to gain private benefits and the risk of punishment is low. Community energy purchase schemes without a system of intermediate rewards and/or risk of punishment might not be as efficient as expected. We further suggest that it is necessary to study the implications of these schemes beyond actual energy use, because opportunistic behavior of others might lead to indirect negative consequences on interpersonal relationships in the community. Future research is needed to understand psychological cost of generous compensatory behavior that we observed in unfair condition, and whether it could spill over to other domains of interactions within community.

While our game modeled one specific case of managing energy supply and demand on a local level, our results have implications to decision-making in other areas of sustainable behavior such as household energy use (Leygue et al., 2014) and climate change mitigation (Milinski et al., 2008). Understanding how people act in dilemmas such as climate change mitigation are of high importance, however, we advocate the approach to employ social dilemmas to study more local decisions, such as community energy purchase schemes. Ultimately, for people, the climate change mitigation dilemma consists of small person-level every day dilemmas, such as the one presented in this paper. Moreover, research suggests that attempts to establish cooperation with large groups is less productive than when small groups are involved (Santos and Pacheco, 2011). Without understanding how to manage free-riding and achieve cooperation on small scale, it will also not be possible to resolve the global climate change mitigation dilemma.

Limitations

Our study had limitations. Failure in experimental software on day 7 meant that all participants whose data were submitted to the final analysis saw the feedback about behavior of others twice, and on the first occasion the feedback was incorrect. This reduced sample size and could have biased the responses that were submitted to the analyses. While our findings are consistent with previous research both in terms of behavioral outcomes (Jacquet et al., 2013) and individual differences (Myrseth et al., 2015; Skatova and Ferguson, 2013), the replication of the main findings can help to affirm the results. The heterogeneity of responses in economic games (which subsequently produces large variation around the mean) is well documented (Burlando and Guala, 2005), however, future research could also help to explain remaining variation that is visible from **Figure 2**'s SE: specifically, there might be other personality or cognitive factors driving variation in behavior in the fair condition.

Our study also did not account for a number of factors that could have impacted cooperation in the collective-risk game scenario: for example, reputation, anonymity, communication between group members, and other factors. Research on social dilemmas suggests that reputation (Milinski et al., 2002) is key in sustaining cooperation in groups. Reputation scenarios assume that players responses could be traced throughout the game, which was not possible in our design. Decreasing anonymity is not directly applicable to energy use at home, as it comes at privacy cost (McKenna et al., 2012; Rouf et al., 2012). However, lower levels of anonymity than we had in our game – where only group-level behavior was shared with others – and some opportunities for reputation building might have improved cooperation in a collective-risk dilemma scenario. Furthermore, our study did not involve any communication between group members, while real-world interactions certainly involve at least some level of communication. Communication provides the group with more opportunities to self-manage cooperation through, for example, imposing social sanctions, such as disapproval (Noussair and Tucker, 2005). Future research could look into whether communication between group partners helps to coordinate the efforts around energy use and reduce the level of opportunistic strategies.

CONCLUSION

We used a social dilemma – a collective-risk game – to model real-world decisions in a community energy purchase scenario. Our study confirms that in order to maintain cooperation the risk of punishment should be high and tangible; otherwise, people take advantage of the situation and free ride. Specifically, individuals high in impulsivity and low in sensitivity to punishment showed higher levels of opportunistic behavior. We also show that when the risk of punishment is high, people compensate for others to avoid the group-level punishment. However, the psychological cost is unclear. Compensating for others could come at an emotional toll and impact negatively on further interactions. Taking advantage at the last moment puts collective good at risk in a way that can lead to a disaster, especially in an environmental context. We suggest that people should have tangible intermittent incentives to save energy and not just be expected to follow what others do as suggested by social norms literature. Taken together, the findings of the study reported here illustrate the benefits of a social dilemma approach to study behaviors around energy use and the constraints of policies in the environmental domain.

AUTHOR CONTRIBUTIONS

AS and BB designed the study, AS and BKS collected and analysed the data, all authors contributed to the writing and revision of the paper, approved the final draft, and agree to be accountable to all aspects of the work presented in the paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at http://journal.frontiersin.org/article/10.3389/fenrg.2016.00008

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Exploring societal preferences for energy sufficiency measures in Switzerland

Corinne Moser[1,2], Andreas Rösch[2] and Michael Stauffacher[2,3]*

[1] *Institute of Sustainable Development, School of Engineering, Zurich University of Applied Sciences, Winterthur, Switzerland,* [2] *Natural and Social Science Interface, Institute for Environmental Decisions, Department of Environmental Systems Science, ETH Zürich, Zürich, Switzerland,* [3] *Transdisciplinarity Laboratory, Department of Environmental Systems Science, ETH Zürich, Zürich, Switzerland*

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****Correspondence:***
Corinne Moser,
Institute of Sustainable Development, School of Engineering, Zurich University of Applied Sciences, Technoparkstrasse 2, Winterthur 8401, Switzerland
corinne.moser@zhaw.ch

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Many countries are facing a challenging transition toward more sustainable energy systems, which produce more renewables and consume less energy. The latter goal can only be achieved through a combination of efficiency measures and changes in people's lifestyles and routine behaviors (i.e., sufficiency). While research has shown that acceptance of technical efficiency is relatively high, there is a lack of research on societal preferences for sufficiency measures. However, this is an important prerequisite for designing successful interventions to change behavior. This paper analyses societal preferences for different energy-related behaviors in Switzerland. We use an online choice-based conjoint analysis ($N = 150$) to examine preferences for behaviors with high technical potentials for energy demand reduction in the following domains: mobility, heating, and food. Each domain comprises different attributes across three levels of sufficiency. Respondents were confronted with trade-off situations evoked through different fictional lifestyles that comprised different combinations of attribute levels. Through a series of trade-off decisions, participants were asked to choose their preferred lifestyle. The results revealed that a vegetarian diet was considered the most critical issue that respondents were unwilling to trade off, followed by distance to workplace and means of transportation. The highest willingness to trade off was found for adjustments in room temperature, holiday travel behaviors, and living space. Participants' preferences for the most energy-sufficient lifestyles were rather low. However, the study showed that there were lifestyles with substantive energy-saving potentials that were well accepted among respondents. Our study results suggest that the success of energy-sufficiency interventions might depend strongly on the targeted behavior. We speculate that they may face strong resistance (e.g., vegetarian diet). Thus, it seems promising to promote well-balanced lifestyles, rather than extremely energy-sufficient lifestyles, as potential role models for sufficiency.

Keywords: energy, sufficiency, societal preferences, routine behavior, lifestyles, conjoint analysis

Introduction

The Importance of Energy Sufficiency for Switzerland's Energy Transition

Countries worldwide are facing challenging transitions of their energy systems with regard to fighting climate change and declining availability of fossil fuels. Switzerland has adopted a new energy strategy (Energy Strategy 2050) that promotes the implementation of new renewables, the stepwise phase-out of nuclear power, and sets ambitious reduction targets for per capita energy consumption (Swiss Federal Council, 2013). This goal shall be achieved primarily through increased energy efficiency, i.e., through the implementation of technologies that require less energy to maintain current levels of services. Examples of such energy-efficient technologies include cars that use less fuel per kilometer and well-insulated buildings that require less heat.

However, there are technological and economical limitations to energy efficiency. Furthermore, increased energy efficiency often causes rebound effects (Herring, 2006; Darby, 2007), which at least partly offset the saved resources (e.g., energy, time, money). For example, although many appliances, such as fridges or TVs, are more energy efficient than ever before, these appliances have also increased in size and/or in number over time. Along these lines, researchers have also found that people rely on symbols of energy efficiency, which may lead to paradoxical effects (Sütterlin and Siegrist, 2014). For example, in an experiment, participants judged a person driving an energy-efficient car (i.e., a Prius) over longer distances to be more energy conscious than an SUV driver who covered shorter distances – and so, in total, consumed less energy than the Prius driver (Sütterlin and Siegrist, 2014).

Thus, in order to guarantee an absolute reduction in energy consumption, efficiency needs to be complemented by more sustainable consumption patterns. This requires behavioral changes on the part of energy consumers. This perspective was confirmed by a recent study in which Notter et al. (2013) estimated Switzerland's potential to become a 2000-Watt/1 ton CO_2 society[1]. The authors conclude that this goal is only realistic "when assuming a pronounced technological increase in efficiency combined with a smart sufficiency strategy" (Notter et al., 2013, p. 4019).

Sufficiency can be understood as a process of changing existing consumption patterns for more sustainable ones. The literature distinguishes two different approaches to sufficiency (for an overview, see Jenny, 2014). First, in a narrow sense, sufficiency can be understood as a necessary complement to energy efficiency and renewable energy sources in order to reach political goals regarding climate targets, resource use, or per capita energy consumption. Second, it can also be understood as a critique of our consumer society and our growth-based economic system, as well as of respective attempts to change these systems (Linz et al., 2002; Linz, 2012). In this study, we focus on the former, narrower understanding of sufficiency: that is, while energy *efficiency* refers to technological means to minimize resource input, energy *sufficiency* refers to changes in individual behaviors that lead to lower demand for energy services. In accordance with Breukers et al. (2013), we understand energy-sufficient behavior to involve changes in routine behaviors and lifestyles that lead to lower energy consumption. Examples of energy-sufficient behaviors include line-drying laundry instead of using a tumble dryer, eating vegetarian food instead of meat, commuting by bike instead of by private car, and so on.

With respect to private energy consumption in Switzerland, over the entire lifecycle of products and services, the domains of mobility, heating, and food are the most energy-demanding (Notter et al., 2013). A study by Jungbluth and Itten (2012) indicated substantial potential for energy-sufficient behaviors in these domains. In their study, the following reduction potentials in primary energy consumption were found: nutrition at around 8% (i.e., eating vegetarian and seasonal food); mobility at around 17% (traveling by bike/walking) or around 11% (traveling by public transport); and living at around 12% (i.e., lowering the room temperature, reducing the living space per person).

To unlock these sufficiency potentials, private consumers are key agents of change. However, private energy consumption patterns are strongly shaped by habits, norms, and cultural, social, and technological contexts and are, therefore, difficult to change (e.g., Owens and Driffill, 2008). Under certain conditions, interventions have the potential to induce such changes (Thøgersen, 2005).

Background: Private Energy-Saving Behaviors and Interventions to Change Behavior

There exists a broad range of research that empirically tests or reviews interventions to change energy-relevant behaviors in different national contexts (Abrahamse et al., 2005; Steg and Vlek, 2009; Mourik and Rotmann, 2013). Steg and Vlek (2009) suggested a general framework for encouraging pro-environmental behavior, which is also relevant in the context of promoting energy-sufficient behavior. To design successful interventions, it is important to identify the relevant behaviors to be changed and to understand how they are influenced. This means that (i) those behaviors that actually have an impact on energy consumption should be identified (Gardner and Stern, 2008; Huddart Kennedy et al., 2015) and (ii) there is a need to better understand "the feasibility of various behavior changes and the acceptability of its consequences" (Steg and Vlek, 2009, p. 310). While (i) can be assessed from a technical perspective, (ii) requires a thorough understanding of people's current energy-saving behavior and their preferences regarding behavior change. In other words, a purely technical approach is not enough to design a successful intervention; it needs to be combined with social-scientific knowledge on behavior and behavior change.

Many studies in Switzerland and internationally that take a social-scientific perspective on energy saving differentiate between curtailment behaviors and efficiency decisions (Gardner and Stern, 2008; Karlin et al., 2012). As the topic of this study is energy sufficiency, we focus on the former aspect. A representative survey in Switzerland analyzed Swiss people's current energy-saving behaviors in the domains of housing, food, and mobility (Sütterlin et al., 2011). People on average perform energy-saving behaviors in the domain of housing very often (e.g., turning the

[1]The 2000-Watt/1 ton CO_2 society is a Swiss energy vision that envisages a more equal distribution of global energy consumption by setting per capita consumption goals, it is very popular among Swiss authorities and academics (http://www.2000watt.ch).

TV off when not watching it, filling the washing machine to its capacity, ventilating briefly but intensely during winter). By contrast, energy-saving behaviors in the domain of food (e.g., avoiding buying foods that are flown in, buying seasonal fruits and vegetables) and, in particular, energy-saving behaviors in the domain of mobility (e.g., going on holidays by train, covering short distances by foot or bicycle) are performed less frequently on average (see **Table 1** in Sütterlin et al., 2011). This study did not cover meat consumption, although this is a crucial factor with respect to energy consumption in the domain of food (Dutilh and Kramer, 2000). The results of this Swiss study are in line with those of a Dutch study (Poortinga et al., 2003) that analyzed the acceptability of different energy-saving measures and found that such behaviors as switching off the lights or appliances are well accepted, while such behaviors as going on holidays by train or altering food patterns were somewhat contested. A study in nine OECD countries focusing on housing identified that turning off lights in unused rooms and fully loading washing machines and dishwashers were the most commonly performed energy-saving behaviors, while switching off stand-by modes in appliances seemed less popular (Urban and Ščasný, 2012). The reported results[2] indicate that private energy-saving behavior is domain dependent and, similarly, that people's preferences for energy-saving measures differ for different domains.

What is more, there is a need to better understand contextual influences on energy consumption to design successful interventions (Steg and Vlek, 2009). Barr et al. (2011) noted with some criticism that studying and promoting sustainable consumption is often focused on isolated behaviors in the everyday "home" context where many pro-environmental behaviors (e.g., turning off lights) are socially desired and require no or only small adjustments in lifestyle. With changing contexts, for example when traveling to holidays, pro-environmental behaviors (e.g., not flying to a distant country) often ask for substantial adjustments in lifestyle that leads to conflicts and trade-offs. From focus group discussions, the authors conclude that, "in short, holidays were 'off limits' to sustainability" (Barr et al., 2011, p. 717). This means that designing successful interventions that actually have an impact on energy consumption requires a comprehensive approach that takes into account different contexts where energy is consumed, such as the home, in transit (e.g., from home to work), and while traveling (e.g., on vacation). At the same time, behavior in everyday situations (e.g., commuting) as well as in extraordinary situations (e.g., traveling to holidays) should be considered.

Goal of this Study

The literature review has revealed that (i) for realizing the energy transition in Switzerland, private consumers are key agents of change, (ii) there exist considerable energy-saving potentials through more energy-sufficient behavior, (iii) appropriate interventions may help unlock these potentials, (iv) an important prerequisite for designing successful interventions is knowing what behaviors have the most impact on energy consumption, how they are influenced by context and what people's preferences are regarding behavior change. While many studies exist that analyze current energy-saving behaviors in Switzerland and in other countries, our study focuses on people's preferences for behaviors that differ in energy-sufficiency. Our approach considers behaviors that have a considerable impact on private energy consumption. Furthermore, behaviors are evaluated together as lifestyles, which are characterized by certain behavior patterns in different domains (everyday mobility, holiday travel, housing, food consumption). Thereby, different contexts for energy-sufficient behavior are considered. In other words, we aim to analyze what people think about energy sufficiency in different domains of life and to which energy-sufficient behaviors they can relate.

The goal of this paper is to identify societal preferences in Switzerland concerning different energy-related behaviors in order to reveal barriers and opportunities related to the promotion of energy sufficiency. Such knowledge provides an important basis for designing successful energy-sufficiency interventions by identifying potential levers and "no-go" areas for such interventions. More concretely, we investigate the following research questions:

- Which energy-sufficiency-related domains and behaviors do people prefer when evaluating different lifestyles?
- Which energy-sufficient lifestyles are perceived to be attractive by the public?

Context Information about Switzerland

As our analysis is focused on Switzerland, we briefly provide some key figures on private energy consumption as well as some context information about the domains we are looking at, that is, commuting, holiday travel, housing, and meat consumption. Swiss households demand 29% of final energy – mostly for heating and hot water – and mobility/transport demands 35% (Swiss Federal Office of Energy, 2014). In the domain of mobility and transport, 74% of final energy is demanded for transporting people on the road, that is, mostly for private mobility (Swiss Federal Office of Energy, 2013). Although Switzerland has an excellent public transport system, approximately half of the inhabitants own a car (536 cars per 1000 inhabitants in 2014; Swiss Federal Statistical Office, 2015d). However, the level of motorization is usually lower in bigger cities compared to rural areas. On average, Swiss commuters commute 14.3 km from home to the workplace (one way). Of these commuters, 53% commute by car, 30% use public transport (train, tram, and bus), 9% bike, and 6% walk (Swiss Federal Statistical Office, 2014). In 2012, Swiss people (older than 6 years) completed a total of 20,300,000 trips with at least one overnight stay, which is roughly three trips per person. The purpose of 65% of these trips was holidays, which people spend abroad (2/3 of cases, 1/3 in Switzerland). Around 50% of trips were made by car and 27% by plane (Swiss Federal Statistical Office, 2013b). The average living space per capita was 45 m^2 in 2013. Around 60% of Swiss people rent their home, while around 40% are homeowners (Swiss Federal Statistical Office, 2015a). In 2012, around 25% of Swiss people ate meat almost every day (6–7 days per week); around 50% ate meat 3–5 days per week, around 20% ate meat 1–2 times a week, and 3% never ate meat (Swiss Federal Office of Public Health, 2014).

[2] While the cited papers all use a quantitative approach, there are various studies on the issue of energy consumption that use more qualitative approaches, such as focus groups (e.g., Barr et al., 2011) or ethnographic research (e.g., Higginson et al., 2014).

Materials and Methods

Conjoint Analysis

We apply a conjoint analysis to determine societal preferences for different fictional lifestyles that are characterized by different levels of energy-sufficient behaviors in relevant domains. Conjoint analysis is a method for studying complex decisions that are characterized by trade-offs among different attributes. This method has classically been used in consumer and marketing research (Green and Srinivasan, 1978) and has recently been applied to energy and infrastructure-related decisions (e.g., Dohle et al., 2010; Krütli et al., 2012; Rudolf et al., 2014). Participants are confronted with decision situations composed of sets of attributes. For example, decisions regarding future energy systems may be characterized by different prices and production technologies. Each attribute is associated with different levels (e.g., levels for price: different prices per kilowatt hour of electricity; levels of energy production technologies: solar, nuclear, wind, and hydropower). Participants are then asked to evaluate the decision situation by providing rankings, which requires them to consider combinations of different attribute levels jointly to make a decision. Next, the relative importance values of the different attributes and the part-worth utilities of all the levels can be assessed.

An advantage of conjoint analysis is that it reflects real-world decisions, which are usually characterized by combinations of criteria. Furthermore, it measures preferences indirectly, thus minimizing the potential for respondents to give socially desired responses (Sattler and Hensel-Börner, 2001). From a methodological perspective, another advantage is that not all combinations of levels need to be evaluated empirically; instead, utilities of all combinations can be estimated based on a limited set of choices.

In this study, a choice-based conjoint (CBC) was applied. The main difference between a CBC and other conjoint procedures is that, in a CBC, rather than ranking or rating different options, participants choose their preferred option (Sawtooth Software, 2008). For assessing choices at an individual level, a hierarchical Bayesian estimation was applied.

Attributes and Levels

For the study at hand, only domains with high-energy-saving potentials were chosen (based on Jungbluth and Itten, 2012; Notter et al., 2013). Specifically, we selected the domains of mobility, heating, and food. For each of these domains, a set of attributes was selected:

- Mobility: distance to workplace, means of transport when commuting, holiday travel behavior.
- Heating: amount of heated living space per person, room temperature.
- Food: weekly meat consumption.

The basis for selecting these attributes was a study by Notter et al. (2013), who analyzed and quantified private behaviors based on their cumulative energy demand (CED), global warming potential (GWP) and environmental impact (EI99) by considering the entire lifecycles surrounding these behaviors. Private car use was the most important influencing factor for all three indicators (38% of CED, 31% of GWP, and 29% of EI99). Additional important influencing factors were heating (26% of CED, 25% of GWP, and 18% of EI99) and food (6% of CED, 15% of GWP, and 20% of EI99). Private aviation accounted for 7% of CED, 5% of GWP, and 6% of EI99 (data based on Notter et al., 2013). Also Jungbluth and Itten (2012) identified substantial reduction potentials for primary energy consumption in the domains of mobility, living, and nutrition.

For each attribute, three different levels were defined based on the literature or on thorough discussions among the authors of this paper, such that Level 1 is set as the least energy-sufficient level and Level 3 is the most energy-sufficient level. In contrast to most existing research, this research makes no explicit reference to energy consumption in its descriptions of lifestyles. Rather, the focus is on concrete social practices, which seems to be a more appropriate measurement for the embedded character of energy consumption. Furthermore, this approach also serves the purpose of describing lifestyles realistically, without the use of extensive technical jargon. **Table 1** provides an overview of the selected domains, attributes, and levels.

Design of Conjoint Analysis and Procedure

The defined attributes and levels served as a basis to describe fictional characters and their lifestyles. These lifestyles were composed randomly by combining different levels (one per attribute, full-profile CBC). In each decision situation, participants were presented with three different lifestyles and then asked to choose their preferred lifestyle (see **Table 2**). The study used a full-profile design, meaning that all attributes (with different levels each time) were represented in every option. For each option, the sequence of attributes was kept constant in order to maintain consistency and to better enable comparisons of levels across options. The study was a forced-choice situation; that is, there was no possibility to not choose an option.

Each participant made 10 choices in total (i.e., 10 decision situations): eight randomized tasks and two fixed holdout tasks (all participants evaluated the same two holdout tasks). The holdout tasks were used to validate the conjoint model (Orme et al., 1997; see Chapter Model Fit). Sawtooth Software was used to conduct the experiments and analyze the results (Sawtooth Software, 2008). Three sample lifestyles are presented in **Table 2**.

The data were collected as part of the second author's master's thesis (Rösch, 2013) in autumn of 2013 in the German-speaking part of Switzerland. Participants were recruited from an online panel and received a small incentive for participation. Potential participants were invited to the study by e-mail. The participants first responded to the 10 CBC tasks described above. Afterwards, they answered questions on their personal energy-related behaviors, as well as socio-demographic questions. On average, participants required 12.5 min to complete the survey. All participants who completed the survey were included in the statistical analyses.

Sample

In total, $N = 150$ participants took part in the study. On average, the participants were 47.7 years old ($SD = 12.67$ years), with youngest participant being 18 and the oldest being 66 years old. 52% ($n = 78$) of respondents were female. A total of 50%

TABLE 1 | Domains, attributes, and levels for the conjoint analysis.

Domain	Attribute	Level	Level description
Mobility	Distance to workplace (Swiss Federal Statistical Office, 2012)	1	100 km from home to workplace (100 km)
		2	10 km from home to workplace (10 km)
		3	2 km from home to workplace (2 km)
	Means of transport	1	Car or motorcycle (car)
		2	Public transport or park and rail (public transport)
		3	Public transport or bike (public transport/bike)
	Holiday travel behavior	1	Short trips in Europe, vacations on another continent, solely air travel (World)
		2	Short trips to cities in adjacent countries, vacations within Europe, air travel for vacations, trains for short trips (Europe)
		3	Short trips and vacations in Switzerland or adjacent countries, train whenever possible or car otherwise (Switzerland)
Heating	Living space (Swiss Federal Statistical Office, 2015a)	1	60 m^2 per person (60 m^2)
		2	50 m^2 per person (50 m^2)
		3	40 m^2 per person (40 m^2)
	Room temperature (Stadt Zürich, 2006)	1	T-shirt can be worn even if cold outside (high)
		2	Thin pullover and trousers are worn if cold outside (medium)
		3	Thick pullover and warm socks are worn if cold outside (low)
Food	Weekly meat consumption (Notter et al., 2013)	1	Meat at least once a day (daily)
		2	Meat 3–4 times a week (3–4 times)
		3	Vegetarian or vegan diet (never)

Terms in brackets indicate the short labels for the levels.

TABLE 2 | Exemplary description of three lifestyles, as presented in the study.

The lifestyles of different people are presented below. Please read through them carefully and choose the lifestyle that appeals to you the most. Click the respective button at the end. Even if it is difficult for you to choose, please select one. (1 of 10 decisions)

Work	The person lives in Zürich and works in Bern. He or she commutes daily (**100 km** one way). He or she would consider moving if a new job involved a commute of more than 130 km each way (e.g., Zürich–Fribourg) He or she commutes to work by **public transport or park and rail**	The person lives and works in Zürich. His or her place of work is **2 km** away from home. He or she would consider moving if a new job involved a commute of more than 10 km each way He or she commutes to work by **car**	The person lives in Zürich and works in Thalwil. He or she commutes daily (**10 km** one way). He or she would consider moving if a new job involved a commute of more than 50 km each way (e.g., Zürich–Olten) He or she commutes to work by **public transport or park and rail**
Travel	The person regularly goes on short trips **within Europe** (e.g., a weekend trip to Rome, London, or Barcelona). At least once a year, he or she travels to **another continent** for vacation (e.g., Maldives, the USA, or Brazil). For short trips and longer vacations, he or she usually takes the **plane**	The person regularly goes on short trips **within Switzerland** (e.g., a weekend trip to Ticino or to the Alps). He or she spends vacations in **Switzerland** or in adjacent countries (e.g., France or Germany). For short trips and longer vacations, he or she usually **uses public transport whenever possible or car otherwise**	The person regularly goes on short trips in **adjacent countries** (e.g., a weekend trip to Paris or Berlin). At least once a year, he or she travels to a more **distant country in Europe** (e.g., Spain or Norway) or to a close country on another continent (e.g., Egypt). For vacation, he or she takes a **plane**, and for short trips, he or she uses **public transport**
Housing	The person's flat offers **50 m^2** per person The colder it gets, the more clothes he or she wears at home to keep warm. On days that are particularly cold, he or she wears **thick clothes and warm socks**	The person's flat offers **40 m^2** per person Even if it is less than 0°C outside, he or she only wears **thin clothes** at home because the rooms are comfortably warm	The person's flat offers **60 m^2** per person Even if it is less than 0°C outside, he or she only wears **thin clothes** at home because the rooms are comfortably warm
Food	The person **consumes meat three to four times per week**	The person **consumes meat daily**	The person does not eat meat; he or she is a **vegetarian or vegan**
	○	○	○

Bolded phrases were depicted in red, and the original descriptions were in German.

of participants had concluded vocational training, 20% had completed higher education (e.g., university, PhD), 16% had completed senior high school, 5% had completed higher vocational training, 4% had completed compulsory school, and the rest did not specify their education level.

Regarding political attitudes, most participants positioned themselves in the center of a left wing-right wing scale [from 1 (left) to 7 (right); $M = 3.98$, $SD = 1.13$]. Most participants (43%) lived in two-people households, 24% lived in single-person households, 16% lived in three-people households, and the remainder lived in households larger than three people.

Table 3 summarizes key characteristics of our sample and compares them to Swiss average data (where comparable Swiss data are available; Swiss Federal Statistical Office, 2013a, 2015b,c).

TABLE 3 | Key characteristics of our sample in comparison with Swiss population statistics.

Key characteristics	Study sample (*N* = 150)	Swiss population
Gender	52% females, 48% males	51% females, 49% males (Swiss Federal Statistical Office, 2015c)
Age (mean)	47.7 years	41.8 years (Swiss Federal Statistical Office, 2015c)
Education	50% vocational training 20% higher education (e.g., university, PhD) 16% senior high school 5% higher vocational training 4% compulsory school Rest: other	44% vocational training 18% higher education (e.g., university, PhD) 9% senior high school 13% higher vocational training 15% compulsory school (Swiss Federal Statistical Office, 2013a)
Household size	24% one person 43%: two people 16%: three people Rest: larger households	35% one person 33%: two people 13%: three people Rest: larger households (Swiss Federal Statistical Office, 2015b)

The sample is approximately representative of Switzerland's population with regard to gender. With respect to vocational and university education, the sample is roughly comparable to the Swiss population, though, in our sample, fewer people had completed only compulsory school and fewer people had completed higher vocational training than the Swiss average. Regarding age, our sample is slightly older than the Swiss average; however, this could be due to the fact that only participants 18 or older were invited to participate in the survey. Regarding household size, more people in our sample lived in two-people households, and fewer people lived in single households than in the Swiss population.

Finally, participants were asked about their personal behaviors in relation to their energy consumption in the domains of mobility, housing, and food. Around 65% of participants lived 10 km away from their workplace or closer, around 30% lived between 10 and 50 km from their workplace, and around 5% lived more than 50 km from their workplace. Most participants (41%) used their car to commute to work, 35% used public transport, 9% used bikes, and 15% walked to their workplace. Over the last 5 years, participants had flown, on average, around nine times ($M = 9.33$, $SD = 10.84$). In terms of living space, 34% of participants used 40 m^2 per person or less, 25% of participants used around 50 m^2 per person, 19% used around 60 m^2 per person, and the remainder used more than 60 m^2 per person. Participants also indicated the general room temperature they used during the heating season in their apartments: around 33% of participants wore only light clothing during the winter time, 37% wore thin pullovers and trousers, and 30% wore thick clothes and warm socks. With regard to food consumption patterns, 21% of participants ate meat at least once a day, 63% of participants ate meat three to four times a week, 12% ate meat one to four times a month, and 4% were vegetarians or vegans.

Results

Model Fit

The validity of the conjoint model is assessed by observing how well part-worth utilities of the levels can predict the evaluations of the two fixed holdout tasks (Orme et al., 1997). We ran a simulation to estimate participants' choices regarding both holdout tasks based on the individual part-worth utilities derived from the eight random tasks. The simulated results for both holdout tasks were then compared with the actually observed choices regarding the two holdout tasks. A mean absolute error (MAE) test was used to calculate the fitness of the model. This means that, for every holdout task, the difference between the predicted and the observed choices was calculated, with a smaller MAE indicating a better model fit. The MAE for both holdout tasks was 4.24, which is a good result for holdout tasks with three options, according to Orme, President of Sawtooth Software (personal communication). The holdout tasks were only used for this analysis; all further analyses include only the eight randomized tasks.

TABLE 4 | Importance of attributes ordered by importance (relative importance values sum to 100%).

Attribute	Relative attribute importance (rounded) (%)
Weekly meat consumption	32
Distance to workplace	22
Means of transport	13
Room temperature	12
Holiday travel behavior	11
Living space	10

Importance of Attributes

All participants who finished the survey were included in the subsequent statistical analysis ($N = 150$). As a first step, the attribute importance values were calculated using Sawtooth Software. Attribute importance is a relative measure that allows a relative comparison among the different attributes used in a study. Relative attribute importance is calculated by dividing the range of part-worth utilities for each attribute by the total utility range for all attributes and multiplying the result by 100%. Therefore, when interpreting importance values, it is important to note that these values are relative to the other attributes in the study and that they depend upon the chosen attribute levels (Orme, 2010). Analyses reveal that meat consumption is the most important attribute for participants, followed by distance to workplace (see **Table 4**). Means of transport, room temperature, holiday travel behaviors, and living space can be considered less important attributes, such that meat consumption is about three times as important as those attributes.

Average part-worth utilities of the levels were calculated and displayed in **Figure 1**. The part-worth utilities of each attribute sum to 0. The negative part-worth utilities were not necessarily disliked by participants; however, compared to the other levels, they were preferred less (all else being equal; Orme, 2010). **Figure 1** again indicates the greater importance of the two attributes – meat consumption and distance to workplace – but also shows the part-worth utilities represented by the different attribute levels. This allows the preferences for different attribute levels to be identified. Regarding distance to workplace, larger commuting distances (100 km) were clearly less preferred over shorter commuting distances (2 km or 10 km). For commuting, bike and public transport were the most preferred means of transportation, while, for travel behavior, no clear preference pattern emerged. Regarding living space, larger apartments were preferred to smaller ones, and lower room temperatures were preferred to higher temperatures. In terms of food, eating meat daily or several times a week was clearly preferred to a vegetarian diet.

Lifestyles that are Sufficiency-Oriented and Perceived as Being Attractive

Based on the aggregated part-worth utilities of all the levels, the overall utilities for all composed lifestyles can be calculated (adding up all part-worth utilities for different combinations of attribute levels; in total, $3^6 = 729$ lifestyle combinations are possible). As can be expected based on the results presented in **Figure 1**, the lifestyle with the highest utility is that of a person who lives around 10 km from work, commutes to work by bike or public transport, takes holiday trips to Europe, lives in quite a large apartment that is not extensively heated during the winter, and eats meat three to four times a week (first rank, overall utility = 123.49). By contrast, the lowest utility is provided by the following lifestyle: a person who lives around 100 km from work, commutes to work by car, makes holiday trips to Switzerland, lives in quite a small apartment that is medium heated during the

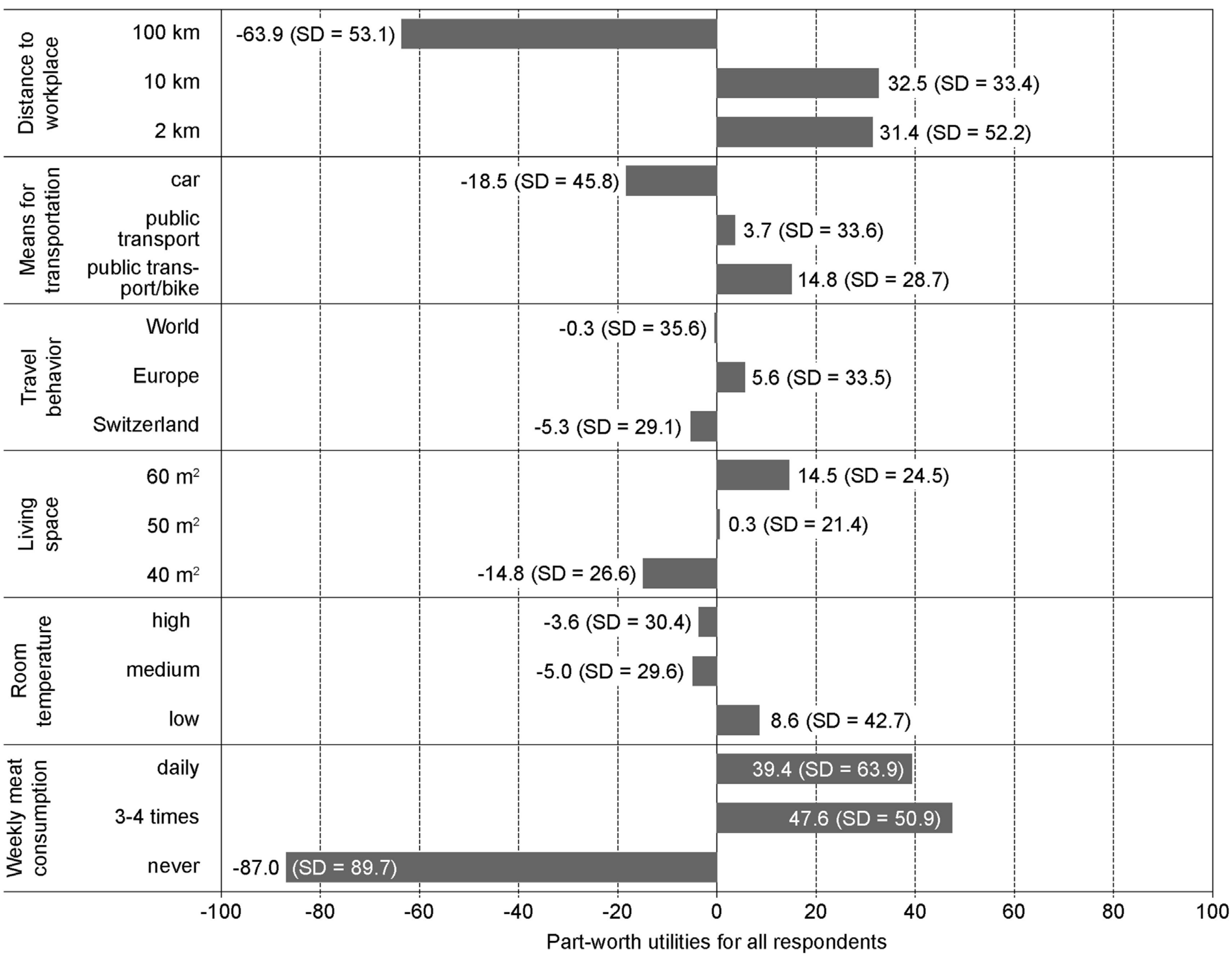

FIGURE 1 | Aggregated average part-worth utilities of all attribute levels. The part-worth attributes for each attribute sum to 0 ($N = 150$).

winter and never eats meat (last rank, overall utility = −194.50; see **Table 5**).

A visual inspection of **Table 5** indicates several important findings: the 10 most popular lifestyles do not include a strictly vegetarian diet, while the 10 least preferred lifestyles all do. Similarly, the 10 most popular lifestyles are characterized by short commuting distances that are traveled by bike or by car, while the 10 least popular lifestyles are characterized by large commuting distances that are traveled by car. Regarding travel, Switzerland does not seem to be a popular destination, and small apartments are not found among any of the top 10 lifestyles. Regarding room temperature, there is a preference for low temperatures.

In order to make judgments about the sufficiency levels of the various lifestyle concepts, we calculated an additive sufficiency index (*S*-index) based on the attribute levels (i.e., for the most sufficient level, three points were calculated; for the mid-sufficient level, two points; and for the least sufficient level, one point). We are aware that this is an estimate that does not account for differences in energy-saving potentials among attributes, since all attributes are weighted equally. However, calculating the exact amount of energy per level is difficult, since some of the levels are described quite vaguely (e.g., in the case of the level "Europe" in the domain of travel behavior, the exact number of trips taken is not specified; moreover, the exact destination location within Europe is not specified). Thus, our *S*-index is a very rough estimate of potential savings. It does not reflect differences in energy-saving potentials between domains (e.g., commuting 2 km to work is weighted the same as never eating meat), and it gives different weights to levels within domains. The *S*-index takes a value between $S_{min} = 6$ and $S_{max} = 18$, with a higher index representing a more sufficient lifestyle. In **Table 5**, the *S*-index is displayed for the 10 most preferred and the 10 least preferred lifestyles. On average, the *S*-index for the 10 most preferred lifestyles is slightly higher than the *S*-index for the 10 least preferred lifestyles, indicating that the most preferred lifestyles are not less sufficient than the least preferred ones; rather, the contrary seems to be the case.

The lifestyle composed of the most sufficient attribute levels is represented by a person who lives around 2 km from work, commutes to work by bike or public transport, makes holiday trips to Switzerland, lives in quite a small apartment that is not heated a lot during winter, and never eats meat. This most sufficient lifestyle is not popular at all – mainly because of its strictly vegetarian diet. It has an overall utility of −52.35 (rank 549 out of 729; see **Table 6**). Thus, the question of interest concerns which sufficiency-oriented lifestyles – specifically, ones that may be less extreme – trigger broad social support and, thus, have the potential to be promising models for energy-sufficient lifestyles for individuals.

Table 6 indicates two key things: first, reasonably energy-sufficient lifestyles can be found among the 50 most preferred lifestyles (11 of the top 50-ranked lifestyles have *S*-indexes of 14 or 15; $S_{max} = 18$). However, the most energy-sufficient lifestyles do not seem to be very popular. Second, our results indicate the biggest potentials for support for sufficiency in the domains

TABLE 5 | Ranking of lifestyles (10 top-ranked and lowest-ranked lifestyles), ordered by overall utility.

	Overall utility	Rank	Distance to workplace (km)	Means of transport	Travel behavior	Living space (m²)	Room temperature	Weekly meat consumption	*S*-index
10 most preferred lifestyles	123.49	1	10	Bike/PT	Europe	60	Low	3–4 times	13
	122.47	2	2	Bike/PT	Europe	60	Low	3–4 times	14
	117.62	3	10	Bike/PT	World	60	Low	3–4 times	12
	116.60	4	2	Bike/PT	World	60	Low	3–4 times	13
	115.30	5	10	Bike/PT	Europe	60	Low	Daily	12
	114.28	6	2	Bike/PT	Europe	60	Low	Daily	13
	112.55	7	10	Bike/PT	CH	60	Low	3–4 times	14
	112.45	8	10	PT	Europe	60	Low	3–4 times	12
	111.53	9	2	Bike/PT	CH	60	Low	3–4 times	15
	111.43	10	2	PT	Europe	60	Low	3–4 times	13
10 least preferred lifestyles	−175.87	720	100	Car	World	40	Low	Never	12
	−177.99	721	100	Car	CH	50	High	Never	11
	−179.40	722	100	Car	CH	50	Medium	Never	12
	−180.94	723	100	Car	CH	40	Low	Never	14
	−182.15	724	100	Car	Europe	40	High	Never	11
	−183.56	725	100	Car	Europe	40	Medium	Never	12
	−188.02	726	100	Car	World	40	High	Never	10
	−189.43	727	100	Car	World	40	Medium	Never	11
	−193.09	728	100	Car	CH	40	High	Never	12
	−194.50	729	100	Car	CH	40	Medium	Never	13

Levels are colored according to sufficiency: white = most sufficient levels; light gray = mid-sufficient levels; dark gray = least sufficient levels. S-Index, sufficiency index, which is calculated by adding points according to level: most sufficient level, 3; mid-sufficient level, 2; least sufficient level, 1. N = 150.

TABLE 6 | Display of those lifestyles within the 50 most preferred lifestyles with the highest energy sufficiency, ranked by overall utility.

Overall utility	Utility ranking	Distance to workplace (km)	Means of transport	Travel behavior	Living space (m²)	Room temperature	Weekly meat consumption	*S*-index
122.47	2	2	Bike/PT	Europe	60	Low	3–4 times	14
112.55	7	10	Bike/PT	CH	60	Low	3–4 times	14
111.53	9	2	Bike/PT	CH	60	Low	3–4 times	15
109.26	15	10	Bike/PT	Europe	50	Low	3–4 times	14
108.24	18	2	Bike/PT	Europe	50	Low	3–4 times	15
103.34	27	2	Bike/PT	CH	60	Low	Daily	14
102.37	31	2	Bike/PT	World	50	Low	3–4 times	14
100.49	37	2	PT	CH	60	Low	3–4 times	14
100.05	40	2	Bike/PT	Europe	50	Low	Daily	14
98.32	46	10	Bike/PT	CH	50	Low	3–4 times	15
97.97	48	2	Bike/PT	CH	60	Medium	3–4 times	14
97.30	51	2	Bike/PT	CH	50	Low	3–4 times	16
82.20	124	2	Bike/PT	CH	40	Low	3–4 times	17
−52.35	549	2	Bike/PT	CH	40	Low	Never	18

Below the straight lines, we show the first occurrences of lifestyles with S-Indices of 16, 17, and 18. The last row displays the most sufficient lifestyle (S-index = 18). Levels are colored according to sufficiency: white = most sufficient levels; light gray = mid-sufficient levels; and dark gray = least sufficient levels. N = 150.

of distance to workplace, means of transport, and room temperature. By contrast, there did not seem to be any support for lifestyles promoting a strictly vegetarian diet and reduced living space per person.

Discussion

Key Findings

This study investigates the societal potentials for sufficiency interventions by investigating people's preferences for different lifestyles using a conjoint analysis. Our first research question is: *Which energy-sufficiency-related domains and behaviors do people prefer when evaluating different lifestyles?* Based on the data from the conjoint analysis, the following patterns are suggested: distance to workplace and meat consumption are considered to be the most important factors when participants make choices regarding their preferred lifestyle. More specifically, participants strongly preferred shorter commuting distances over longer distances and eating meat several times a week over a vegetarian diet.

Our second research question is: *Which energy-sufficient lifestyles are perceived to be attractive by the public?* Our data suggest that there are lifestyles that are reasonably energy-sufficient and, at the same time, able to attract broad public support. These lifestyles are characterized by short commuting distances, using bikes and public transport for commuting and lowered room temperatures during the heating season. Lifestyles characterized by a strictly vegetarian diet and reduced living spaces per person were the least preferred ones.

Discussion of Key Findings and Potential Implications

As demonstrated in our conjoint analysis, there is a disparity between the most energy-sufficient and the most preferred lifestyles. However, this does not mean that energy sufficiency and popular lifestyles must necessarily conflict. There are lifestyles that are both widely preferred and relatively energy-sufficient. Our research has shown that people weigh such domains as mobility, heating, and food differently when making choices about their preferred lifestyles, indicating that they make different trade-offs between these domains. In the following, we separately discuss all of the domains, their potentials for energy sufficiency and possible implications for practice (e.g., for interventions). However, it must be kept in mind that these results were established in an integrated and, thus, indirect way. Also, results are strongly influenced by the attributes and levels chosen and are situated in the context of the German-speaking part of Switzerland.

Shorter Commuting Distances and Mode of Transport

Our results suggest a preference for shorter commuting distances. This is likely because shorter commuting distances provide significant benefits to individuals in the sense that shorter commutes give employees more leisure time. Similarly, our results suggest a preference for biking to work. This preference may also relate to individual benefits, since "active commuting" (i.e., biking to work) is positively related to physical well-being (Humphreys et al., 2013). Our results reflect a trend in Swiss cities (e.g., Zürich) in which an increasing number of households refrain from having a car, instead opting to use bikes, public transport, or car sharing. In Zürich, 48% of households do not own a car, and the rate of motorization has declined since the 1990s to around 350 cars per 1000 inhabitants (Stadt Zürich, 2012). This is almost certainly due to the city's excellent public transport system, which offers regular, punctual, and modern means of transport. Our results indicate a high social acceptance for commuting by bike or public transport – and, as such, suggest the potential for interventions to reduce energy consumption through commuting. For example, campaigns that promote biking to work (Bike to Work, 2013), sharing offers (e.g., car sharing, bike sharing), or even car-free lifestyles (e.g., car-free residential areas) may be effective. As the level of motorization in the rural areas of Switzerland is still high compared to that in urban areas (Swiss Federal Statistical Office, 2015d), it might be particularly promising to develop respective interventions for rural areas. One interesting example is the bike-4car campaign, which encourages car owners to give up driving and try out e-biking for free for a period of 2 weeks[3]. It is important to note that the success of interventions to change commuting behavior depends strongly on the available infrastructure, such as quality of public transport and spatial separation of activities (e.g., shopping, sports, daycare; Thøgersen, 2005). This implies that our results are very context-sensitive and might look very different in another country.

Travel Behavior

Our study indicates that, relative to the other attributes, holiday travel behavior was not a very important attribute. Our study does not indicate large social support for more local travel behavior; however, this option was perceived as only slightly less attractive than vacations and short trips in Europe or on other continents. We can only speculate about why this might be the case. One reason could be that, although locations varied, all levels seemed to include many short trips and holiday opportunities over the year. Therefore, the different levels might have been perceived as equally attractive, leading only to a small spread across the levels.

Living Space and Room Temperature

Our study indicates a preference for large living spaces, since 60 m^2 per person is clearly preferred to 40 m^2 per person. Moreover, our results follow a clear trend in Switzerland toward larger living spaces (Swiss Federal Statistical Office, 2015a). One crucial question is how to address the need for more personal space within cities, where such space is particularly scarce. One option would be to complement a limited amount of personal space with shared spaces (e.g., shared guest rooms, workshops, office spaces, and common rooms). Such shared rooms offer benefits on several different levels: (i) in total, less space needs to be heated, lighted, etc., thus reducing energy consumption; (ii) people can profit from shared infrastructure; and (iii) shared rooms address people's need to connect with other people, in that they offer opportunities to meet, exchange, and learn from each other. Since this approach (i.e., increasing the usage of shared spaces while limiting personal space) addresses different needs and does not only focus on reduced energy consumption, it is particularly promising in terms of attracting broad social support (International Energy Agency, 2014; Moser et al., 2014). Regarding room temperature, the study indicates a certain potential for interventions to reduce room temperature, since lower room temperatures were preferred to higher temperatures. However, it should be noted here that the study was conducted in autumn, before the heating season; thus, the results may be framed by the time of year. Interestingly, the results of our study indicate paradoxical effects regarding living space and room temperature that are similar to those determined by Sütterlin and Siegrist (2014). They found that participants regard a person who has more living space but lower room temperatures to be more environmentally conscious than a person with less living space but higher room temperatures, although the latter actually uses less energy for heating.

Meat Consumption

Our results clearly show that a vegetarian or vegan diet is not a viable option for the vast majority of participants. For most participants, it was important to eat meat several times per week or even daily. However, the results also showed that daily meat consumption is not the most preferred option, indicating that many people are ready to refrain from meat consumption from time to time. A link to personal health may play an important role here. Based on our results, we may speculate that restrictions on eating meat might trigger strong reactions and protests. Instead, campaigns promoting vegetarian dishes from time to time may be more effective. Furthermore, people might be nudged into less energy-intense dietary habits through attractive alternatives in canteens and restaurants (Bucher et al., 2011).

Critical Reflections, Limitations and Further Research

In our study, we see three particular limitations related to: the choice of levels, context influences, and the construction of the *S*-index.

In conjoint analyses, the importance values of attributes are vastly influenced by the levels and the spread associated with the attributes. Although Orme (2002) suggests that levels should spread across the full range of possibilities, this might have been too extreme for the meat consumption attribute. As shown in **Table 4** and **Figure 1**, the importance of the meat consumption attribute was significantly influenced by the negative part-worth utility of the level of vegetarian diet (never). In comparison with the other levels (i.e., daily meat consumption and three to four times meat consumption per week), this option is more extreme because it suggests a strictly vegetarian or vegan diet. It is possible that a less extreme level (e.g., meat consumption once a month) would not have triggered such extreme reactions by participants. On the other hand, our responses are in line with the intense public response that followed the proposal by some Swiss canteens to launch "vegetarian days." This announcement resulted in large protests in social media and through online comments to media articles, indicating that meat consumption may be non-negotiable for many Swiss people. Although daily consumption is not necessarily desired, many people in Switzerland are not ready to completely give up meat consumption. In 2012, only around 3% of Switzerland's population never ate meat or sausage products (Swiss Federal Office of Public Health, 2014). For a future study, it would be interesting to add another level between never and three to four times a week, such as once a month or on special occasions. A similar logic regarding the spread of levels can be found in the attribute commuting distance, since the commuting distances of 2 and 10 km are quite close together, while 100 km is more extreme. It would be interesting to include a less extreme option in a future study, thereby allowing the identification of tipping points in preferences with respect to commuting distances.

[3] www.bike4car.ch

It is likely that our study results are affected by contextual influences. These influences may have manifested, in particular, in participant responses to the attribute room temperature. Here, many participants preferred lifestyles in which the protagonists wore warm clothes during winter to keep warm in their apartments, instead of turning up the thermostat. This result may have been influenced by contextual effects, since the data were collected in September and not during the heating season. Furthermore, the amount of clothing worn serves only as a proxy for drawing conclusions about the actual room temperature (in terms of absolute values). It could be that people prefer warm clothing, but simultaneously heat their living spaces to higher temperatures. However, we would argue that it is easier for participants to imagine the types of clothes implied by room temperature than to imagine a particular room temperature in degree celsius. Similarly, our results regarding travel behavior could be influenced by the season in which the study was conducted. If the study had been conducted before summer, when many people in Switzerland usually plan longer vacations, preferences for flying to distant countries might have been more distinct. In general, actual behaviors cannot be inferred directly from the revealed preferences, as there might be additional constraints in people's lives. For example, although a participant might prefer a commuting distance of 2 km, he or she may not be able to move closer to the workplace or change jobs due to his or her family situation.

Although our *S*-index provides certain indications regarding the energy-saving potentials of the presented lifestyles, these indications offer only a very rough estimate, which does not account for differences in the potential savings of the attributes. For future research, it would be interesting to describe the levels more precisely. More finely grained data would facilitate the calculation of the actual energy-saving potentials of the presented lifestyles (e.g., based Life Cycle Assessment databases), thus allowing us to draw precise conclusions about the energy-saving potentials of the most preferred lifestyles.

Conclusion

Our study results suggest that the success of energy-sufficiency interventions might depend strongly on the targeted behavior. Interventions to change certain behaviors (e.g., meat consumption) seem likely to face strong public resistance. As such, our results have implications for the promotion of energy-sufficient lifestyles through, for example, energy-saving campaigns. Specifically, our results show that extremely energy-sufficient lifestyles are not perceived as attractive – or, more technically speaking, they are characterized by a negative overall utility. We thus speculate that the promotion of such extremely energy-sufficient lifestyles might backfire, potentially evoking resistance or resignation.

Our study results could be interpreted to suggest that well-balanced lifestyles with substantive (but not extreme) energy-saving potentials might better serve as social models for energy sufficiency (compared to extremely sufficient lifestyles). As role models, such well-balanced lifestyles may motivate people to change their routine behaviors and lifestyles in order to consume less energy. A similar effect was found in a study on scenarios for urban development, in which the most sustainable scenarios were unable to trigger consensus among different stakeholders (e.g., investors, urban planners, housing target groups), whereas more balanced scenarios were able to gain broader support (Bügl et al., 2012). However, the study at hand is exploratory; thus, questions concerning exactly how the public reacts when confronted with extreme energy-sufficient lifestyles or respective interventions, what types of emotions these lifestyles trigger and how well different groups identify with them remain unanswered. Field experiments could be a promising approach to investigate these questions.

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The climate change problem: promoting motivation for change when the map is not the territory

Idit Shalev *

Department of Education, Zlotowski Center of Neuroscience, Ben-Gurion University of the Negev, Beer Sheva, Israel
**Correspondence: shalevid@bgu.ac.il*

Edited by:
Tobias Brosch, University of Geneva, Switzerland

Reviewed by:
Michael Richter, University of Geneva, Switzerland

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The climate-change risks that have emerged in the wake of mass industrialization indicate the need for a transition to sustainable energy, but attempts to encourage people to adopt pro-environmental behavior often achieve only limited success (Whitmarsh and O'Neill, 2010; Chu and Majumdar, 2012). Indeed, despite the wealth of evidence that an energy transition is critical to our very survival, people in general are reluctant to change their energy related decisions and behaviors. I suggest that the key to understanding our stunted ability to address the problem of climate change is rooted in human motivation, which is defined as the process that moves individuals to action. Motivational barriers, which imply difficulties in energy, direction and action initiation, can be illustrated by the analogy of a car, which requires fuel as its energy source and a steering system to provide direction; without both, it cannot move (Deci and Ryan, 1985). Similarly, motivational processes are impelled by two modes of action: one, automatic, effortless and involving no conscious awareness, is responsible for people's immediate responses to the environment. The second is voluntary and conscious, and it mainly helps people navigate and plan for the future direction (Bargh, 1997; Baumeister and Bargh, 2014). From this perspective, the phenomenon of motivation for change is influenced by both implicit and explicit processes and determined by the energy required to navigate in a new direction and the extent to which resistance to change can be overcome (Prochaska and DiClemente, 1986). In what follows, I will describe the unique challenges associated with motivation for change in terms of the two modes of goal pursuit, first by examining the conscious, explicit difficulties associated with making climate change goal and implementing the corresponding means and then by describing the effects of automatic, implicit processes on immediate goal pursuit. Finally, based on social psychology perspective of motivation and strategic principles of psychological intervention, I will provide several recommendations for promoting the energy transition.

EXPLICIT GOAL PURSUIT

A clear sense of direction, essential to implement the behavioral change needed to promote an energy transition, is at the core of the ability to govern or to direct attention, resources, or action toward the realization of a particular goal (Higgins, 1989). Insofar as it is defined as a cognitive representation of a desired end-point that affects evaluations, emotions, and behaviors (Fishbach and Ferguson, 2007), a goal entails information about desired end-states that serve as reference points toward which behavior is directed (Carver and Scheier, 1981; Kruglanski et al., 2002; Shah et al., 2002).

The climate change problem, however, is exceptionally amorphous, providing no clear direction for goal pursuit in the quest for solutions. Therefore, much of the public discourse about climate change comprises critical evaluations of alternative goals or means to decide which should be pursued to achieve the aims of climate change control. Ample research in the field of social psychology suggests that chronic involvement in assessment and evaluation as opposed to movement from state to state is associated with paralysis and inaction (Kruglanski et al., 2000, 2010; Shalev and Sulkowski, 2009). Similarly, research has demonstrated that perceived threat inhibits one's readiness to have new experiences and to try unfamiliar directions. Individuals who feel they are under threat, therefore, tend to neglect their long-term, future planning goals in favor of the short-term goal of self-defense. Because the presence of threat stimulates the motive to reaffirm rather than to change the self, individuals typically resist the challenge entailed in altering their habitual behavior (Steele, 1988; Cohen and Sherman, 2014). As such, the presence of threat reduces individual readiness to modify judgment in the light of new evidence (Kruglanski, 1989). Likewise, the greater the ambiguity of the situation, the greater the need for a rapid answer (Kruglanski and Webster, 1996; Kruglanski, 2004), which breeds resistance to change as revealed in the real-world proclivity for political conservatism among many decision makers (Lewin, 1951; Jost et al., 2003).

Extending this line of thought, the pursuit of solutions to the climate change problem has motivational consequences for one's energy estimation and economy of action. Insofar as energy for goal pursuit is constrained by limited attentional resources (Kruglanski et al., 2002), the availability of energy to invest in behavior guided by a volitional change of habit is limited. Theories on goal-gradients suggest that short-term goals may undermine long-term goals because the strength of goal activation increases as a function of physical (e.g., Hull, 1932) or temporal proximity to the goal (Markman and Brendl, 2000). Therefore, investing energy in a distant goal is perceived as more costly, which helps explain why individuals prefer to conserve their energy for causes perceived as essential.

IMPLICIT GOAL PURSUIT

The climate change problem lacks important defining features such as geographic location or deadline. For example, climate deterioration has been defined using multiple terms (e.g., global warming, climate crisis, or climate change) interchangeably, indicating the absence of a clear direction in public discourse (Schuldt et al., 2011). Research has shown that given this uncertainty, individual orientation vis-à-vis global warming may be shaped by an alternative, automatic route to goal pursuit that functions without involving one's conscious awareness. Under such a scenario, external environmental stimuli trigger relevant mental representations that effect immediate action, but people are not, and usually remain, unaware of the influence exerted by those stimuli (Bargh et al., 2010; Loersch and Payne, 2011; Bargh et al., 2012). For example, the exposure to heat-related primes and to anchors for future rises in temperature increased the level of belief in climate change and the willingness to pay to combat global warming (Joireman et al., 2010; Risen and Critcher, 2011). The automatic mode of goal pursuit suggests that activation caused by physical experiences automatically spreads to their associated mental representations and may subsequently influence climate change decisions and behaviors (Bargh and Shalev, 2012; Meier et al., 2012). Likewise, there is evidence that estimated energy for action was automatically influenced by physical cues of thirst and dryness such that individuals reported greater fatigue and lower vitality, increased thirst, and decreased persistence in task completion. Taken together, these results suggest that the perception of somatic state automatically affects goal pursuit and may implicitly affects our motivation to change habitual behavior (Shalev, 2014).

CAN WE INFLUENCE THE ENERGY TRANSITION?

Thus far, we have examined the explicit and implicit motivational difficulties entailed in making decisions about the climate change problem and then in implementing the appropriate behavioral changes to address the problem. In his seminal work on the ecology of mind, Bateson (1972) argued that "the map is not the territory," suggesting that the potential usefulness of future script is not a matter of its literal truthfulness, but rather, its utility relies on the extent to which its structure is similar to that of the territory itself. Because of the non-linear, infinite nature of cybernetics, a volitional plan could only be a partial representation of reality. Thus, goals should be close to the surface and structured within a flexible system that enables continuous change. From this theoretical perspective, the strategic approach of systemic psychological intervention is guided by a basic assumption that resolution of the problem does not require that it be fully understood. The general idea is that the solution serves as a "skeleton key" that can be used to unlock multiple problems (de Shazer, 1988, 1994). Based on this perspective, while the proposed solution may not match the problem exactly, the solution should be small enough that the system will accommodate the solution, which will move the system in a slightly different but preferable direction (de Shazer, 1994; Shoham et al., 1995).

Following this view and despite ambiguous end-states, policy makers should invest more energy in encouraging behavioral change that promotes more sustainable resource use than in engaging in the chronic evaluation of possible future end states. One strategy to increase energy for change is to exploit positive message framing to provide incentives for action initiation (Tversky and Kahneman, 1981; Custers and Aarts, 2005). Likewise, research findings indicate that gain-framed messages are more reassuring than loss-framed messages, and therefore, the former will help reduce the stress generated by ambiguous conditions and increase the willingness to adopt new behavioral directions (Rothman and Salovey, 1997). Based on the logic that expected incentive increases motivation for change, communication and regulations (e.g., carbon pollution standards) should be framed in terms of benefits rather than costs.

At the individual level, environmental policies should use external cues as sources of automatic action generation to increase the strength of the association between person and environment (Shalev and Bargh, 2011). Despite evidence that a positive attitude toward environmental protection does not align closely with one's behavior (e.g., Bamberg and Möser, 2007; Nigbur et al., 2010), the exposure to pro-environmental messages and the offering of incentives to use products that are in line with an energy transition may elicit more positive automatic evaluations and subsequently promote the consumer choices of individuals in their daily lives.

To strengthen the direction of action initiation, domestic policy should be occupied more with goal striving than with planning and anticipation (Gollwitzer, 1996). Because of the highly controversial nature of the climate change problem, policy should be designed inclusively by going beyond the immediate issue of problem resolution. For example, the goal of promoting healthy human-nature interaction by improving people's lifestyles could be associated with the corresponding means of attainment and with sub-goals in multiple domains (e.g., environment, health, economy, education, and science). The result is a goal system, associated with each other such that the pursuit of the energy transition goal will be perceived as complementary to the pursuit of other agree upon goals. Such a system of goals comprises incentives, increases action initiation and contributes to the immediate greater good of individuals and firms (e.g., subsidizing conservation technology and hybrid cars; encouraging research of new technologies). Similarly, the use of multifinal means (Kruglanski et al., 2013) may, in addition to the goal of energy transition, help attain other, less controversial or more inclusive goals, in so doing reducing the resistance for change.

Based on this reasoning, to increase motivation for change, policy efforts should create incentives for firms and individuals to pursue the most cost effective options for combatting climate change over time among all sectors, across national borders, and in the face of significant uncertainty. Well-designed national greenhouse gas mitigation policies can serve as the foundation for global efforts and as an example for emerging and developing countries. Following this view, international policy should link climate change initiatives with other contemporary values and interests (e.g., support in developing countries, international commerce, and import regulation). Likewise, cost certainty can be implemented as insurance against sudden, unexpected expenses and to reduce ambiguity.

CONCLUSIONS

This paper presents a motivational perspective to the climate change problem, in the process showing the relevance of explicit and implicit processes in the decision-making and behavioral implementation phases. The approach was based on the assumption that the ambiguity of the condition entails an inherent absence of defining features that can be used to guide our decisions about how to approach the problem. As a result of such ambiguity, people typically concentrate their energy on risk assessment rather than on taking action. However, based on the reasoning that "the map is not the territory" and that the problem need not be fully understood to resolve it, strategies that promote behavioral change should be encouraged. These strategies, which may serve as "skeleton keys," should also include positive message frames to increase people's energy for change, construct a system of goals that is more inclusive than the climate change problem and defined in terms of desired end states, provide incentives to promote energy transition behaviors, and increase the visibility of pro-environmental messages to generate more positive automatic evaluations that will result in environmentally friendly consumer choices.

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Unlocking the potential of smart grid technologies with behavioral science

Nicole D. Sintov[1]* *and P. Wesley Schultz*[2]

[1] *Department of Psychology and Environmental Studies Program, Viterbi School of Engineering, Information Sciences Institute, University of Southern California, Los Angeles, CA, USA,* [2] *Department of Psychology, California State University San Marcos, San Marcos, CA, USA*

Smart grid systems aim to provide a more stable and adaptable electricity infrastructure, and to maximize energy efficiency. Grid-linked technologies vary widely in form and function, but generally share common potentials: to reduce energy consumption via efficiency and/or curtailment, to shift use to off-peak times of day, and to enable distributed storage and generation options. Although end users are central players in these systems, they are sometimes not central considerations in technology or program design, and in some cases, their motivations for participating in such systems are not fully appreciated. Behavioral science can be instrumental in engaging end-users and maximizing the impact of smart grid technologies. In this paper, we present emerging technologies made possible by a smart grid infrastructure, and for each we highlight ways in which behavioral science can be applied to enhance their impact on energy savings.

Keywords: smart grid, energy conservation, energy efficiency, behavioral science, human factors, technology adoption

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Correspondence:
Nicole D. Sintov,
Department of Psychology and Environmental Studies Program, Viterbi School of Engineering, Information Sciences Institute, University of Southern California, 4676 Admiralty Way, Suite 1001 Marina del Rey, CA 90292, USA
sintov@usc.edu

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Background and Significance

Smart grid systems are rapidly being deployed across the world. Although smart grid technologies vary considerably, they generally share common potentials, all of which contribute to a more reliable grid: to reduce energy consumption via efficiency and/or curtailment, to shift use to off-peak times of day, and to expand distributed storage and generation options. In each of these areas, human behavior is integral to unlocking the full potentials of these smart grid technologies.

At its core, a smart grid system involves high-resolution meters for quantifying electricity consumption. However, metering infrastructure alone will not result in improved efficiency. In the 1980s, automatic meter reading (AMR) technology advanced power systems by enabling remote collection of electricity use data at higher resolution than manual readings. Building on AMR, advanced metering infrastructure (AMI) technology involves meters that collect near real-time consumption data ("smart meters"). Importantly, AMI networks also enable two-way data communication between utilities and consumers. The ability to interact with consumers in real-time is one key route for engaging consumers with techniques from behavioral science. This connectivity has spawned a variety of new programs and technologies that require consumer adoption and proper use to function optimally. Traditionally, although utilities have involved end-users to some extent in power systems, consumers have often not been central considerations in technology or program design, and in some cases, their motivations for participating in such systems have not been fully appreciated. Consequently, there is a glaring need to understand the ways in which individuals interact with smart grid systems. Leveraging behavioral science can advance our knowledge of how to partner with customers in the smart grid and ultimately lead to more efficient uses of energy.

TABLE 1 | Behavioral science tools for unlocking potentials of smart grid technologies.

Smart grid technology	Potential	Target behavior	Behavioral science tools
Demand response	Reduce peak demand	Increase program enrollment	Incorporate motivators/barriers into messaging; use flexible defaults
Time-of-use pricing plans	Reduce peak demand	Increase program enrollment	Incorporate motivators/barriers into messaging
Energy feedback	Increase energy efficiency	Reduce energy consumption	Leverage social influence; tailor feedback to address barriers/motivators
Disaggregation technologies	Increase energy efficiency	Reduce energy consumption	Provide high-resolution feedback and specific recommendations
Smart automation	Reduce peak demand	Maximize participation in demand response events	Use flexible defaults
Electric vehicles	Distributed storage	Increase adoption and program enrollment	Leverage social influence and symbolic attributes; reduce barriers, including providing financial incentives; use flexible defaults
Solar panels	Distributed generation	Increase adoption	Leverage social influence and symbolic attributes; reduce barriers, including providing financial incentives

Behavioral Science in the Smart Grid

Historically viewed as engineering challenges, power systems have benefited from integrating behavioral science perspectives. For instance, a number of recent reviews have applied behavioral science to better understand the theoretical underpinnings of energy use behavior (Steg and Vlek, 2009), explore the effectiveness of interventions aimed at reducing energy and other resource use (Abrahamse et al., 2005; Abrahamse and Steg, 2013), identify predictors of alternative energy resource acceptance (Perlaviciute and Steg, 2014), and propose models of sustainable energy technology acceptance (Huijts et al., 2012). Building on the existing literature, this paper focuses on consumer adoption and optimal use (i.e., using the technologies in a manner that maximizes energy savings and/or peak load reductions) of emerging technologies in smart grid systems.

In the sections below, we briefly review selected models from behavioral science that aid in understanding the adoption and use of smart grid technologies. The models selected are not intended to provide an exhaustive list, but rather to illustrate some of the major conceptual and theoretical approaches that can help to inform smart grid programs. We then provide an overview of several strategies that utilize smart grid infrastructure to encourage electricity savings among residential users. We summarize specific examples, discuss the underlying behavior change tools at work, and suggest ways in which these strategies can be improved by leveraging behavioral science, offering practical advice for researchers and practitioners alike. See **Table 1** for an overview.

Behavioral Foundations

There is a large and growing body of research on theoretical models that have been proposed for understanding energy use behaviors. Although a detailed theoretical synthesis is outside the scope of this paper, we selected several models that have received considerable empirical support in explaining various pro-environmental behaviors, and can be extended to better understand smart grid technology adoption and use. We link each of the models described below to one or more of the smart grid technologies discussed later in this paper:

- The Theory of Planned Behavior (TPB) postulates that behavior is proximally determined by intention to perform the behavior, which is more distally predicted by attitudes, normative beliefs, and perceived control (for details see Ajzen, 1991).
- The Norm Activation Model (NAM) posits that altruistic behavior begins with learned social norms regarding proper behavior, which give rise to personal norms tied to self-concept (Schwartz, 1994). When a person is aware of the consequences of her/his behavior, and ascribes responsibility for these consequences to the self, personal norms become "activated," and the person will behave in accordance with them.
- The Value-Belief-Norm (VBN) theory builds on the NAM, suggesting that value orientation predicts environmental worldview, awareness of consequences, and ascription of responsibility, which in turn gives rise to norms, which more proximally predict behavior (Stern, 2000).
- Focusing more closely on social norms, The Focus Theory of Normative Conduct (Cialdini et al., 1990) differentiates between two primary types of social norms: (1) descriptive norms, which convey what others typically do in a particular situation; and (2) injunctive norms, which convey social approval or disapproval for a given behavior. The model proposes that the impact of norms on behavior depends on which norms are most salient to an individual in a given situation (e.g., Schultz et al., 2007).
- The field of Behavioral Economics also offers insights to help explain why people make decisions that do not always maximize their expected utility or economic benefit (Kahneman, 2003). This approach takes into account the influence of information processing biases on decision-making, such as choice framing effects (i.e., framing a choice as either a gain or a loss) and default policies (i.e., opt-in vs. opt-out).
- Under the framework of Self-Determination Theory, supporting an individual's autonomy, competence, and relatedness (connection with others) fosters motivation that can increase the likelihood of engaging in a variety of behaviors (Deci and Ryan, 1985).

- The Theory of Operant Conditioning states that behavior that is reinforced or rewarded tends to be repeated, behavior that is not reinforced, and moreover, behavior that is punished, tends to become extinguished (Skinner, 1953).
- Diverging a bit from the above models, Community-Based Social Marketing (CBSM; McKenzie-Mohr, 2000) is a framework for behavior change that involves identifying motivators and barriers to the acceptance and adoption of a particular behavior among a given population, and devising tailored strategies to enhance motivators and overcome barriers. This approach has been used successfully to promote a range of pro-environmental behaviors, ranging from recycling to water efficiency to energy conservation (for detailed review of CBSM programs, see McKenzie-Mohr and Schultz, 2014). We view CBSM as one promising approach to promoting the adoption and utilization of smart grid technologies due to its flexibility and potential to address aspects of all aforementioned models.

In the remainder of this paper, we discuss how these models can be used to understand and expand the adoption and use of several smart grid technologies. Previous work has classified energy conservation behaviors into efficiency and curtailment categories (Gardner and Stern, 2008). Curtailment involves using existing equipment less frequently or intensively but requires repetition of curtailment behaviors to achieve savings. On the other hand, efficiency behaviors typically involve infrequent capital improvements and do not require the same level of repetition or behavioral maintenance. We view the smart grid technologies described below as falling into the efficiency category if they require infrequent actions on the part of the consumer and/or primarily involve utility direct control of equipment (i.e., direct control demand response, smart automation, electric vehicle adoption, and solar panel installation), whereas technologies in the curtailment category require ongoing participation by consumers to achieve energy reductions (i.e., voluntary curtailment demand response, time-of-use pricing programs, energy feedback, disaggregated feedback).

Demand Response Programs

Electric power interruptions often result from demand exceeding available supply. Even relatively brief lapses in power reliability have significant consequences. Estimates for annual economic losses from power interruptions include €150 billion among European Union businesses and $80 billion in the United States (LaCommare and Eto, 2004). Because demand varies by time of day, growing efforts are being made to manage demand by reducing peak loads as an alternative to the traditional strategy of bringing on additional generation, usually from higher-polluting energy sources (California Independent Systems Operator, 2013). Accordingly, U.S. utilities are investing $700 million annually in demand response (DR) strategies to curtail peak loads and thereby make more efficient use of the existing generation and transmission infrastructure (United States Energy Information Administration, 2015a). Although DR forecasting models predict when, where, and how much energy will be used, solving the key problem of reducing peak demand requires programs that encourage electricity consumers to make behavioral changes.

In alignment with the curtailment vs. efficiency framework, utility DR programs generally fall into one of two categories: (1) voluntary curtailment, which involves appealing to consumers to temporarily curtail consumption by changing behavior in real-time in response to alerts (e.g., California Independent Systems Operator Flex Alerts); or (2) direct control, in which consumers permit utilities to remotely control home equipment (e.g., Southern California Edison's air conditioning cycling program). Voluntary curtailment programs generally rely on behavioral prompts and appeals in their attempt to persuade consumers to curtail usage. However, generic informational appeals to save energy have not been particularly effective for reducing overall energy use (e.g., Schultz et al., 2007; Nolan et al., 2008; Schultz, 2010). Findings from studies of persuasion suggest alternatives for enhancing participation rates and reducing demand, for instance by tapping into social norms (Schultz et al., 2007; Nolan et al., 2008) or obtaining commitments.

Even when applying effective tools of persuasion, voluntary curtailment still relies on consumers to undertake a series of decisions and actions, including: (1) attending to the alert, (2) mentally cataloging energy use in home, (3) deciding what action(s) to take to reduce energy use, (4) executing such actions, and (5) maintaining this lower level of use over some period of time. This multi-step process requires mental, physical, and additional resources, and must be repeated for each DR event. There may be benefits to this repetition: previous work has found that people look to their own past pro-environmental actions as a signal of their own environmental identities, potentially resulting in positive spillover to other behaviors (Van der Werff et al., 2014). Because voluntary curtailment provides people with many opportunities to engage in energy conservation efforts, it may foster environmental identity and lead to performance of other environmentally beneficial behaviors.

To maximize impact, however, it is also important to consider longevity of savings and accuracy in curtailment forecasting (i.e., efforts to predict the magnitude and temporal and geographic distribution of load reduction for upcoming DR events, which are critical for maintaining power reliability). Because people often have inaccurate perceptions about the impacts they can make with various energy conservation behaviors (Attari et al., 2010), leaving curtailment choices to consumers may result in smaller or less reliable reductions than a direct control approach, even among motivated consumers. On the other hand, while direct control systems permit less consumer choice, they may be associated with lower variability in curtailment levels, thereby improving curtailment forecasts. Under many direct control programs, participating in DR events is the default choice, eliminating the need for consumers to repeatedly go through the previously described process, and often requiring no action at all on the part of end-users. Research from the field of Behavioral Economics has demonstrated that people are significantly more likely to select default options (Johnson and Goldstein, 2003), including those related to electric power (Pichert and Katsikopoulos, 2008), and direct control DR systems leverage this principle. Additionally, in simplifying the load curtailment process via automation, direct control programs also require less ongoing effort of end-users, which could potentially support savings over longer periods of time.

Despite the strength of direct control programs in achieving reliable reductions, their appeal can be marred by privacy and autonomy concerns. Among the most notable concerns are perceptions that utilities can use smart grid technologies to (1) directly control a variety of home equipment without consumer permissions or opt-out options; and (2) infer specific behaviors in which occupants are engaging, such as cooking or eating (Krishnamurti et al., 2012; Hess, 2014). In a similar vein, a recent study found that consumers preferred the option of choosing how to curtail consumption to direct control technologies (Leijten et al., 2014). These finding are in alignment with the TPB, which states that perceived control is an important predecessor of behavior. Accordingly, direct control programs that do not foster a sense of control will likely have lower program enrollment compared to DR programs that do so.

To gain greater acceptance, direct control systems should cultivate a sense of consumer control. This could potentially be accomplished by providing some level of consumer choice. What may be indicated is a flexible control strategy, allowing consumers to retain control of home equipment while also maintaining the accuracy of load predictions via default settings that maximize curtailment. This can be achieved by developing systems that allow for consumer override, flexibility in curtailment levels, and other consumer adjustments; these parameters should also be accounted for in curtailment forecast models. It is equally important that consumers recognize that they can adjust such systems—and that participation benefits the environment. For some consumers, however, voluntary curtailment may remain a more attractive option. Identifying moderating variables that differentiate the impacts of types of consumers, DR strategies, and contextual influences on technology adoption is a growing area to which behavioral science can contribute.

Flexible control DR strategies may offer one path forward, but program enrollment represents a significant barrier to participation, and overcoming this barrier is not trivial. Current DR program participation rates are estimated at less than 10%, and actual compliance rates are likely lower (United States Federal Energy Regulatory Commission, 2009). Achieving the load reduction objectives of the coming decades will require increasing levels of consumer engagement. Toward this end, utility-consumer connectivity must be enhanced. For instance, it has been recommended that programs shift from a one-way, utility-to-consumer approach to a more interactive relationship (Vine et al., 2013). Using CBSM to identify motivators for program participation, and building these into recruitment strategies, could boost enrollment rates.

Time-of-use Pricing

Another smart grid tool that can reduce peak load is variable pricing plans. For instance, time-of-use (TOU) pricing plans aim to discourage energy use during peak times of the day by charging more during high-use periods (typically mid-afternoon hours) and less during off-peak hours. Under TOU programs, usage tends to shift to off-peak times, but the total amount consumed generally remains consistent (Lutzenhiser et al., 2007). By applying financial incentives, these programs invoke operant stimulus control to reduce consumers' peak energy use, specifically by punishing (with higher prices) on-peak use and reinforcing (with lower prices) off-peak use (Skinner, 1953). A large body of research has shown that reward can be effective in promoting behavior change, especially while incentives are in place, and reward have been effective in reducing home energy consumption below baseline use levels (Hayes and Cone, 1977; Walker, 1979; Winett et al., 1979; McClelland and Cook, 1980) as well as below levels of information-only and control groups (Winett et al., 1979; Midden et al., 1983).

Despite the potential for reward to reduce demand, energy savings associated with reward have been shown to wear off (McClelland and Cook, 1980) and even to rebound after reward are withdrawn (Walker, 1979). For TOU pricing, if off-peak price breaks cannot be sustained long-term, energy loads typically return to pre-TOU pattern. This effect has been observed across a variety of behaviors, including recycling (Wang and Katzev, 1990), hand washing among healthcare workers (Pareira das Neves et al., 2004), and smoking cessation (Donatelle et al., 2004), and may suggest behavioral habituation. One promising alternative can be found in Self-Determination Theory, which suggests that providing reward for behavior that might otherwise occur through intrinsic motivation can weaken intrinsic motives, and may ultimately reduce the performance of the target behavior (Deci and Ryan, 1985). In other words, reward can be counterproductive over the long-term if they undermine intrinsic motivation to act.

Combining reward with other behavior modification strategies in a way that facilitates transition of the contingency from external reward to internal factors may be a more effective long-term strategy. For example, one approach is to identify underlying values as indicated by the Value-Belief-Norm Theory. CBSM offers a vehicle for identifying these values and developing an intervention with which they resonate. Such interventions have been found to be more effective in promoting pro-environmental intentions than simple information alone (Bolderdijk et al., 2013). Historically, utilities have relied heavily on financial incentives to drive consumer behavior, but this is slowly changing with availability of newer technologies that leverage other principles of behavior change. Given the cost of incentives and their potential to undermine long-term goals, we recommend that reward be applied to one-time actions or to behaviors that are performed infrequently, rather than recurring actions.

Energy Feedback

The proliferation of smart electric meters, most of which record energy data in intervals of one hour or less, has greatly expanded the possibilities for partnering with consumers. First, providing immediate feedback mitigates the issue that people are generally more responsive to immediate rather than future consequences, which arises from the fact that most consumers pay for energy long after using it (Frederick et al., 2002). Smart meter data can be made available in near real-time to consumers through a variety of platforms, including websites, mobile phones, and in-home displays, enabling consumers to connect their behavior with its consequences. The more granular energy data has enabled utilities to advance from providing energy feedback as part of monthly (or even annual) billing to providing near real-time data that can enhance usability and relatability.

Utilities generally view this feedback as a form of education, but evidence from behavioral science shows that feedback can be a very powerful tool for changing behavior. Studies suggest that personalized feedback can produce significantly more energy savings than merely providing educational materials about household energy use (Seligman and Darley, 1977; Midden et al., 1983; Hutton et al., 1986). In addition, smart meters offer higher resolution feedback, which has been found to produce greater levels of energy conservation (Ehrhardt-Martinez et al., 2010), highlighting this potential of the smart grid to support energy efficiency.

Energy feedback represents one type of feedback, but with energy data of entire consumer bases, utilities can also provide feedback about the performance of others, thereby conveying normative information. A growing body of research has shown that descriptive normative feedback—information about what others are doing—can be associated with behavior change (Cialdini et al., 1990; Schultz et al., 2007; Goldstein et al., 2008; Nolan et al., 2008; Abrahamse and Steg, 2013). Under the Theory of Planned Behavior, Norm Activation Model, Value-Belief-Norm Theory, and Focus Theory of Normative Conduct, this may occur through enhancing normative beliefs in support of conservation. In addition, as per the Focus Theory of Normative Conduct, combining descriptive normative feedback with an injunctive message—feedback that conveys social approval—can mitigate the undesirable "boomerang" effect that arises when an individual increases use after receiving feedback that others are consuming more. For instance, Schultz et al. (2007) found that among households using less energy than average at baseline, those who received descriptive normative feedback only increased their use, but this effect was attenuated among those who also received injunctive feedback (in this case, a smiley face affirming lower use than average). This is a relatively new area of research, but findings suggest that building social tools into the delivery of energy data offers considerable promise in efforts to improve energy efficiency. Refinement of social feedback tools requires a better understanding of several potential moderators: type of social feedback, household characteristics (e.g., household size), sociodemographic considerations such as income, and psychosocial factors such as group cohesion (Abrahamse and Steg, 2011, 2013).

Disaggregation Technologies

Moving beyond household-level feedback, technologies that provide energy feedback at the appliance level are coming to market. One option is through smart appliances, which monitor and report their level of consumption, but which are often cost-prohibitive. Another option is non-intrusive load monitoring, which disaggregates the household energy signal into individual appliance loads. Non-intrusive load monitoring is only possible with high-resolution consumption data such as that provided by smart grid technologies.

The level of specificity offered by appliance feedback marks a significant innovation from whole-house feedback, which, while useful when compared to on-bill feedback, falls short of providing information on specific behaviors consumers can undertake to conserve. Household-level feedback still requires consumers to generate a mental list of what is using energy in their home, which can be overwhelming and ultimately inhibit action. Eliminating the need for this process, appliance-level feedback instead informs consumers of exactly which appliances are consuming energy, enabling them to associate discrete behaviors with energy (and sometimes cost) impacts. Disaggregation can also offer a straightforward action step, which may lead to an enhanced sense of competence or perceived control, as suggested by Self-Determination Theory and Theory of Planned Behavior, respectively.

Combined with specific recommendations for improved efficiency and conservation, disaggregated feedback is a promising strategy. However, to date, few studies have evaluated the effectiveness of such technologies on load-shifting and conservation, in part because such systems are so new. Future research in this area is needed.

Smart Automation

Some smart appliances such as thermostats and dishwashers offer more than just appliance-level feedback; they also offer scheduling capabilities and DR signal automation (the ability to be directly controlled by utilities). Technologies such as Internet-enabled programmable thermostats are outfitted to dovetail with direct control DR strategies to curtail peak loads, in addition to offering conservation potential. These technologies can function as "set and forget," requiring minimal ongoing effort on the part of the end-user after initial device purchase, installation, and set-up. As mentioned, research suggests that the conservation potential of efficiency technologies is greater than that of curtailment approaches (Gardner and Stern, 2008). Automation removes the need to sustain behavior change over time, reducing end-user burden and increasing predictability of curtailment outcomes, which is important for improving the accuracy of demand forecasting and supporting power reliability.

However, it is also important to point out that effort is only one of several important factors predicting adoption and optimal use of smart automation and other efficiency technologies. Behavioral science can help address additional challenges in technology design and adoption. For instance, in line with the Theory of Planned Behavior and Self-Determination Theory, devices should foster a sense of control and autonomy, for instance, with user-friendly designs and ease of operation. Similarly, for products that permit utility control, flexible default and remote control settings that allow for consumer modifications should be developed (see Demand Response section above).

Electric Vehicles

Electric vehicles (EVs) offer potential for supporting grid reliability. Specifically, vehicle battery technologies that discharge energy back into the grid during high usage periods offer potential for distributed storage networks and a fundamentally new strategy for managing peak demand. In such a system, AMI technology collects data on vehicle charging schedules, which can be used to generate intelligent, automated charging and discharging schedules that dynamically accommodate grid-wide demand fluctuations. Because each vehicle battery has relatively low storage capacity, widespread consumer adoption is a necessity for making this possible. Globally, less than 1% of light-duty passenger vehicles are EVs (Trigg and Telleen, 2013). For EVs to plug into the smart grid as a viable distributed storage technology, using behavioral science to increase consumer adoption of EVs, as well as enrollment and optimal participation in charge–discharge programs, are critical.

As an emerging technology, EVs face financial, technical, and social barriers to broader consumer acceptance. Perceived costs, including financial and convenience, are among the strongest barriers to adoption (Bockarjova and Steg, 2014). Because purchasing a car tends to be a relatively infrequent behavior, the use of financial incentives, such as government subsidies and tax breaks, is likely to be helpful for increasing EV adoption. The availability of financial incentives is positively correlated with EV adoption rates, but price signals represent only one predictor of EV adoption (Bockarjova and Steg, 2014; Sierzchula et al., 2014). Even among consumers with favorable attitudes toward EVs, reduced range and long charging times are among the top concerns, and many consumers report unwillingness to compromise on these features (Ewing and Sarigöllü, 2000; Hidrue et al., 2011). However, the same consumers are willing to pay high, up front premiums for EVs with longer ranges and faster charging capabilities (Hidrue et al., 2011), highlighting that price breaks alone are not sufficient to increase adoption rates. Symbolic attributes, which signal the impact of a belonging on one's identity and social status, have also been identified as a key factor underlying EV purchase, over and above practical considerations such as cost and range (Heffner et al., 2007; Noppers et al., 2014). Campaigns that tap into these identity concerns may contribute to higher adoption rates.

Diffusion of Innovations theory suggests that social influence also plays an important role in the adoption of new technologies (Rogers, 2003). Under this model, the first 2.5% of individuals to adopt a technology (Innovators) tend to rely on technical information, followed by the Early Majority, who incorporate the opinions of others in their decision-making about new technologies. More Early Majority individuals will be acquiring EVs as the EV market share expands, and therefore harnessing the power of social influence is indicated. Recent research has demonstrated the success of social influence in promoting engagement in a variety of sustainable behaviors, but most of these studies have focused on changing low-cost, habitual behaviors (Schultz et al., 2007; Goldstein et al., 2008; Nolan et al., 2008). Energy efficiency technologies such as EVs involve one-time or infrequent behaviors and high up-front costs, yet offer long-term energy conservation potential and require minimal ongoing effort from consumers. Research is needed to investigate whether social influence can effectively be used as a tool of persuasion in such contexts.

Another consideration is that drivers may object to having their batteries drained during high-use periods, a barrier to charge–discharge programs. As with direct control DR and smart automation, it is essential that flexible rules be developed to permit some consumer control in charge–discharge programs, and that consumers retain a sense of control. Using approaches such as CBSM to uncover additional barriers and motivators to participation in such programs will be critical in crafting strategies to increase enrollment.

Solar Panels

By offering on-site, distributed generation, the excess of which can be routed to overstressed portions of the grid, residential solar panels fit into the smart grid by offering another strategy to boost grid reliability. Currently, however, solar accounts for less than 5% of energy generated in the United States (United States Energy Information Administration, 2015b). As with EVs, for solar to be a viable distributed generation option, consumers must adopt the technology on a considerably wide scale; because solar panels offer long-term savings without ongoing consumer efforts, increasing installations is currently a key issue. High up-front costs and technical considerations represent barriers to this being a reality. Financial incentives may be well-suited to increasing residential solar installations, but alone will not address all barriers to adoption. For instance, recent findings suggest that social influence plays an important role in the installation of rooftop solar systems. Described as the "solar contagion" effect, studies have found that adding a solar system, which is usually visible to passersby, to a single home in a neighborhood significantly increases the average number of installations within a half-mile radius (Bollinger and Gillingham, 2012; Graziano and Gillingham, 2014). As per the Theory of Planned Behavior, Norm Activation Model, Value-Belief-Norm Theory, and Focus Theory of Normative Conduct, a social influence approach like this can strengthen normative beliefs in support of solar panel installation, and contribute to elevated adoption rates. In addition, solar panels are often very visible features of a home, perhaps conveying to others something about the occupants' identities and/or social status. Behavioral science should identify potential symbolic attributes of solar systems, as tapping into these may also support higher adoption rates.

Conclusions and Future Directions

In summary, behavioral science can play an important role in unlocking the potentials of smart grid technologies to reduce overall energy consumption, curtail peak demand, and expand distributed storage and generation options. There is a growing body of research focused on the behavioral aspects of energy consumption, and findings from this research can be overlaid on programs that leverage the emerging smart grid infrastructure. As reviewed in this paper, behavioral science is already being used and can be further leveraged to improve DR programs, time-of-use pricing, energy use and disaggregated feedback, smart automation, and distributed storage and generation options through EVs and solar panels.

In this review, we described how different theories can be used to explain the adoption and use of different smart grid technologies. As has been pointed out previously in relation to other environmentally-relevant behaviors (Huijts et al., 2012; Perlaviciute and Steg, 2014), we believe there is value in developing a more integrated approach to explain the acceptance, adoption, and use of smart grid technologies. Such a framework can guide researchers and practitioners in the application of relevant theories to varying contexts, technologies, consumer characteristics, and behaviors. For instance, such a framework could aid in understanding, and potentially facilitating, spill-over effects: how does adopting and/or using one smart grid technology translate to the adoption and/or use of others? A recent study based on the Norm Activation Model suggests that general awareness of the impact of energy use on the environment, belief that one can mitigate these impacts, and a sense of moral obligation to do so can motivate a variety of energy reduction behaviors (Van der and Steg, 2015). In addition, because different factors appear to foster adoption and use of different smart grid technologies, it is also important to identify the role of moderators on several levels: household characteristics, sociodemographic variables, and psychosocial variables (Abrahamse and Steg, 2011, 2013). Segmenting consumers to identify what technologies resonate best with whom, in what situations, can maximize savings.

A central consideration in partnering with consumers in the smart grid relates to persistence of behavior, which influences energy savings and power reliability. Available data show that effects of behavioral curtailment strategies tend to taper off over time, leading to questions about the long-term value of these strategies. On the other hand, efficiency strategies such as direct control DR, smart automation, EV adoption, and solar panel installation are not subject to the same limitations. How to move consumers past the higher up-front costs, privacy/autonomy concerns, and technical barriers commonly associated with efficiency technologies is a key question for behavioral scientists. We advocate for flexible control strategies that involve utility-set defaults and remote control options (e.g., smart appliances in DR direct control and EVs in charge–discharge programs), while also allowing consumers the freedom to modify these settings.

In addition, there is a growing need for rigorous program evaluations, publicized results, and expanded opportunities for utilities and behavioral scientists to connect. Future work should investigate outcomes beyond kWh savings to explore underlying processes of behavior change. Findings from this work will offer further insights for optimizing the potentials of the smart grid.

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To make people save energy tell them *what* others do but also *who* they are: a preliminary study

Michele Graffeo[1]*, *Ilana Ritov*[2], *Nicolao Bonini*[3] *and Constantinos Hadjichristidis*[3,4]

[1] Department of Information Engineering and Computer Science, University of Trento, Trento, Italy, [2] Department of School of Education and Center for Rationality, Hebrew University, Jerusalem, Israel, [3] Department of Economics and Management, University of Trento, Trento, Italy, [4] Research Centre for Decision Making, Leeds Business School, Leeds University, Leeds, UK

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***Correspondence:**
Michele Graffeo, Department of Information Engineering and Computer Science, University of Trento, Via Sommarive 9, 38123 Povo, Trento, Italy
michele.graffeo@unitn.it; michele.graffeo@gmail.com

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A way to make people save energy is by informing them that "comparable others" save more. We investigated whether, one can further improve this nudge by manipulating *Who* the "comparable others" are. We asked participants to imagine receiving feedback stating that their energy consumption exceeded that of "comparable others" by 10%. We varied *Who* the "comparable others" were in a 2 × 2 design: they were a household that was located either in the same neighborhood as themselves or in a different neighborhood, and its members were either identified (by names and a photograph) or unidentified. We also included two control conditions: one where no feedback was provided, and one where only statistical feedback was provided (feedback about an *average* household). We found that it matters *Who* the "comparable others" are. The most effective feedback was when the referent household was from the same neighborhood as the individual's and its members were not identified.

Keywords: social norms, comparative feedback, nudge, identified victim effect, pro-environmental behavior

Introduction

One way to achieve a cleaner, healthier environment is by investing in green technologies such as smart lamps, solar cells, and electric cars. Developing such technologies is costly, but their cost is eventually offset by environmental benefits. A complementary way is by persuading citizens to conserve energy. But how can this be achieved? Psychological research suggests that there are two routes to persuasion, a "central route" that appeals to people's minds and a "peripheral route" that appeals to people's gut instincts (Petty and Cacioppo, 1981). A particularly effective way to persuade people to conserve energy is by informing them that "comparable others" consume less (see Ferguson et al., 2011; Rabinovich et al., 2012). A study on towel reuse in hotels, for example, compared the effectiveness of the sign "JOIN YOUR FELLOW GUESTS IN HELPING TO SAVE THE ENVIRONMENT" followed by the indication that 75% of other guests in that room reused their towels against the standard sign "HELP SAVE THE ENVIRONMENT" (Goldstein et al., 2008, Exp. 1). The first sign triggered a towel reuse rate of 44.1% against the standard sign's 35.1%. Interestingly, people do not realize the influence that norms have on their behavior (e.g., Nolan et al., 2008), suggesting that these operate through the peripheral route. Importantly, such interventions are easy to implement—it suffices to place doorhangers with the appropriate message in people's homes or hotel rooms—and come at a low cost.

Here, we ask whether we can further improve people's energy saving behaviors by manipulating *who* the "comparable others" are. We asked Israeli students[1] to imagine receiving a message stating that their energy consumption level exceeded that of a comparable household by 10%. They had to state whether they intended to modify their energy consumption (Yes/No) and, if yes, by what amount. We manipulated the referent household along two dimensions in a 2 × 2 design: (1) *Social distance*: the household was located in the participant's neighborhood (in-group) vs. in a different neighborhood (out-group); (2) *Identification*: its members were identified by name, age, and a photograph (identified) vs. they were presented in an abstract way (unidentified). Following research, which we will unpack below, we expected to observe the highest intention to reduce energy consumption when the referent group was from the same neighborhood and identified (Identified—In-group combination).

The introduction proceeds as follows. First, we present additional research showing that messages of what most others *do* ("descriptive norms") and/or what most others *should do* ("injunctive norms") promote energy saving behavior. Next, we focus on research suggesting that people are more willing to comply with a request to help in-group members rather than out-group members and identified rather than unidentified individuals. Then, we combine these lines of research and present the current hypothesis.

The Role of Social Norms in Promoting Energy Consumption

In a clever field study, the littering behavior of people returning to pick their cars from a parking lot was monitored (Cialdini et al., 1990). The experimenters positioned a large handbill under each car's windshield wiper and in alternate times they manipulated, how clean the parking lot was (very clean vs. heavily littered). The variable of interest was how often the subjects littered (threw the handbill on the parking floor) in each condition. Perhaps unsurprisingly, subjects were less likely to litter when the parking lot was clean than when it was dirty. In the same study, the experimenters also manipulated the extent to which subjects' attention was focused on the parking floor. A confederate walked in the direction of the subject holding a handbill. In some occasions, the confederate threw the handbill on the parking floor when in close proximity to the subject whereas, in others occasions the confederate walked by the subject without littering. Interestingly, people were least likely to litter when the confederate littered an otherwise clean parking floor and most likely to litter when the confederate littered a heavily littered parking lot. The idea is that the act of littering drew the subjects attention on the parking floor activating the appropriate descriptive norm: most others do not litter (clean parking floor) or most others do litter (heavily littered parking floor). The authors also discussed the possibility that a clean parking floor might instead activate an injunctive norm, i.e., that people ought to keep the parking lot clean (for another study on the role of injunctive norms, see Hilton et al., 2014).

Social norms do not require direct observation, but can also be triggered through printed messages about what others are doing (for a recent meta-analysis on the effectiveness of various techniques of social influence including social norms and comparative social feedback, see Abrahamse and Steg, 2013). In an ingenious field study on energy consumption, the experimenter team left messages in doorhangers at people's homes (Schultz et al., 2007). The messages reported whether the household's consumption level was below or above that of the average household. The effectiveness of these messages was measured against real meter readings before and after the intervention. Consumers that received negative feedback consumed less in the next period. However, consumers that received positive feedback consumed more in the following period (this is known as the "boomerang" effect). The message is clear: People make adjustments in the direction of the descriptive norm. In a follow up study, the authors found a way to beat the boomerang effect. Together, with the normative feedback they included an emoticon—a happy face for low-consumers or a frowning face for high-consumers—which communicated what people should be doing. With the emoticons in place, not only did the high-consumers consume less but also the low-consumers stayed low!

The Role of Social Distance and Identification

The main experimental goal of the present study was to link the literature on the identified victim effect with literature on the influence of social norms. Specifically, we investigated how the social distance from the referent group (in-group vs. out-group) and the level of identification of the referent group (identified vs. unidentified) combine to influence energy saving behavior. Because, as far as we know, there are no studies that have addressed the interactive effect of these factors on energy saving (but see last paragraph of this section), we develop our hypothesis by focusing on research in another domain, generosity. Generosity is linked to norm adherence—being generous to others can be seen as adhering to a social norm about helping others.

People treat others differently (mostly better) when they belong to their in-group as opposed to their out-group. Numerous studies show preferential treatment and greater generosity toward member of one's own group. People also treat others differently (mostly better) when these are identified rather than unidentified (Schelling, 1968). For instance, people are more willing to comply with a request to donate money to a person in need when the person is described in detail (identified victim) rather than when the person remains unidentified, a "statistical" victim (Jenni and Loewenstein, 1997; Small and Loewenstein, 2003; Kogut and Ritov, 2005a,b; Small et al., 2006; Slovic, 2007;

[1] A typical university student in Israel lives in a shared flat with other students. This should be especially true for most participants in our sample for two reasons: (1) about half of the them stated that, they lived on their own or with a single other person, (2) their mean age was 25.4, at which age most students do not live in their parents' home. Critically, students living in shared flats are responsible for paying their utility bills.

Cryder and Loewenstein, 2010; Cryder et al., 2013). Importantly, studies suggest that these factors interact. Kogut and Ritov (2007), for example, found that willingness to comply with a request to donate in favor of a single identified individual is greater than willingness to help a group of individuals, but only when the perceivers regard the victims as belonging to their own in-group: identifying tsunami victims by name increased actual contributions only when the specified target was a single compatriot.

This effect was also demonstrated in a lab experiment with randomly generated groups (Ritov and Kogut, under review, Study 1). Following the classic minimal group paradigm (Tajfel et al., 1971) participants were asked to rank three pictures in terms of aesthetic pleasantness. Next, they were assigned to one of two groups presumably on the basis of their picture ranking (in reality, the experimenters implemented random assignment). Subsequently, participants played a dictator game against a member of either their in-group or their out-group. The dictator game involves two players: a dictator and a receiver. The dictator is endowed with a sum of money (e.g., 20$) and is given the option to allocate part of it to the receiver. Each player gets paid according to the dictator's allocation. Perhaps unsurprisingly, dictators allocated more money to receivers from their in-group than from their out-group. It is noteworthy to mention that economic rationality mandates that dictators should keep all the money for themselves. In this study, the in-group/out-group manipulation was crossed with whether the receiver was identified/unidentified (by the receiver's experimentally assigned number). Overall dictators were more generous to identified rather than to unidentified receivers. Importantly, however, the main effects of Social distance and Identification were qualified by a significant interaction. Dictators were most generous to in-group—identified players, and equally (un)generous to everybody else.

Although these two factors have not been explicitly addressed in energy consumption studies, the authors of the towel reuse study examined the effect of different referent categories (Goldstein et al., 2008; see also Ferguson et al., 2011). In their Experiment 2, the descriptive norm sign that a subject received was attached to one of four categories: fellow guests, fellow guests that stayed in the exact same room as the subject (the room number was provided), fellow citizens, or men and women. The highest towel reuse rate was observed when the descriptive norm was attached to fellow guests that stayed in that exact room (49.3%). The other conditions showed similar towel reuse rates with an average of 42.8%. As a means of examining, the underpinning mechanism of this effect, Goldstein and colleagues asked a separate group of 53 participants to rate how important it was to their identity being a member of the following categories: an environmentally concerned individual, a hotel guest, a citizen, a male or female, or a guest in the particular room in which they were staying. They found that the last category—which promoted the highest norm compliance—was at the bottom of the participants' lists! Once again, this shows that signs containing descriptive norms persuade people via the peripheral route. For the present purposes, note that the category that worked best was highly "identified."

Present Research and Hypothesis

The aim of the present research was to investigate the comparative effectiveness of four different types of interventions on self-rated intentions to conserve energy. All interventions involved a printed message stating that the individual's energy consumption exceeded that of a referent household by 10%. What varied across the interventions was the information regarding the referent household. Motivated by the research reported in the previous section, we varied this information along two dimensions: (1) *Social distance*: whether the referent household was in the same neighborhood as the subject's (in-group) vs. in a different neighborhood (out-group); and (2) *Identification:* whether the individuals of the referent household were identified by name, age, and a photograph (identified) vs. such information was omitted (unidentified). Merging the research on descriptive norms with that on in-group/out-group, and identified/ unidentified, we expected to observe the highest energy saving in the In-group—Identified condition. Furthermore, we included two control conditions (see below), which aimed to act as a baseline. Our purpose was to measure the effectiveness of the four communication strategies against two baselines: one where only statistical feedback is provided and one where no feedback is provided.

Following a traditional line of research in judgment and decision-making (Kahneman and Knetsch, 1992; Kahneman and Ritov, 1994; Kahneman et al., 1998, 2000; Sunstein et al., 2002), the focus of the present study was to examine people's intentions to conserve energy, rather than actual behavior. The present study is the first to examine the combined effect of social distance and identification on people's intentions to conserve energy.

Study

Method

The experiment was performed in accordance with the ethical standards laid down by the 1964 Declaration of Helsinki. We followed the relevant guidelines of the Hebrew University of Jerusalem regarding questionnaires on decision making and social psychology experiments. None of our questions collected sensible data, therefore the University tacitly approved the study. Participants were 334 university students living in Jerusalem (216 participants provided demographic details: 58% of them were females; $M_{age} = 25.4$ years old, years, $SD = 3.17$, age range: 20–40), and data were collected over two adjacent semesters. A preliminary analysis shows that the collection period had no influence on the variables of interest so we run all the following analyses on a single set of data. The participants were contacted at the Hebrew University of Jerusalem by a research assistant. The experiment was run in labs and common rooms of the university. In the first collection period, participants were randomly assigned to one of four experimental conditions, which resulted by crossing the Social distance of the referent household with the level of Identification of its members in a 2 × 2 design. The resulting conditions were: In-group—Identified, In-group—Unidentified, Out-group—Identified, and Out-group—Unidentified. In the second collection period, we

FIGURE 1 | Picture of the identified referent apartment (participants in the identified conditions also received information about the names and ages of these individuals).

also included two control conditions, and participants were randomly assigned to one of the six resulting conditions. In what follows, we first present the methods and results concerning the four experimental conditions. Subsequently, we describe the control conditions, and how the results from the experimental conditions compare to those of the control conditions.

Experimental Conditions

In all experimental conditions, participants read a scenario that described the energy consumption behavior of a typical three-student apartment. In the in-group conditions, participants read that the referent apartment was located in their neighborhood (somewhere in Jerusalem), whereas in the out-group conditions that it was located in another city (Haifa). In the identified conditions the name, age, and a photograph of the three students living in the household were provided (see **Figure 1**), whereas in the unidentified conditions such information was omitted. Participants were then asked to select whether they intended to increase, keep at the same level, or decrease their energy consumption. If they selected to modify their energy consumption, they had to state by how much in terms of a percentage value. We also presented a list of possible means by which the participants could reduce their energy consumption (see below) and we asked them to select three means and rank them in terms of how much they were willing to implement them (i.e., first, second, and third action most likely to be implemented).

Below, we present the instructions used for the In-group—Unidentified condition, followed by the question pertaining to the willingness to modify current consumption level. The original materials were in Hebrew, below we provide the English translation. The instructions for the other conditions are presented in Supplementary Material.

Imagine that the letter containing your energy bill has arrived. You open it and notice that together with your energy bill there is also a statement comparing your latest consumption level to the average consumption level of a typical apartment from your neighborhood (that is, an apartment where three students live).

The statement notes that: Your energy consumption exceeded the typical apartment consumption in your neighborhood by 10%.

In light of this statement, what do you plan to do? Please tick the option that applies below. If you select option 1 or 3, please specify also the appropriate level.

1. *I plan to increase my energy consumption by approximately _____ %*
2. *I do not plan to either increase or decrease my energy consumption.*
3. *I plan to decrease my energy consumption by approximately _____ %*

If you selected option 3 (decrease your energy consumption level), please specify the means by which you aim to achieve this by ticking up to three statements from the list below. Next to each of these statements, please indicate how much you are willing to actually implement these solutions: "1" = most likely to implement; "2" = second most likely to implement; "3" = third most likely to implement.

- *Turn off the light when you exit the room.*
- *Substitute the old light bulbs in your house with low consumption ones.*
- *Do the laundry during off-pick hours.*
- *Substitute high consumption electric appliances (e.g. dishwashers, irons) with more energy efficient models.*
- *Air dry dishes instead of using your dishwasher's drying cycle.*
- *Turn off your computer and monitor when not in use.*
- *Wash only full loads of dishes and clothes.*

Following these tasks, participants were asked a series of ancillary questions whose objective was to check the perceived effectiveness of the manipulation: (1) "To what extent do you consider important (for your energy consumption choices) the information given above about the typical apartment?" (7-point response scale from 0 = *Not important at all* to 6 = *Very important*); (2) "To what extent do you feel that the place where you live is similar to the typical apartment in your neighborhood (that is, to an apartment where three students live)?" (7-point response scale ranged from 0 = *Not similar at all* to 6 = *Very similar*); (3) "Including yourself, how many people live in your apartment (answer "1" if you live alone; "2" if you live with just one other person; etc.) _____"; (4) "How does your actual energy consumption level compare to the consumption level of other apartments in your neighborhood that have a similar composition to yours (that is, other apartments with the same number of individuals)?" (7-point response scale ranging from −3 to +3; −3 = *My consumption is much lower*, 0 = *My consumption is similar*, and +3 = *My consumption is much higher*); (5) "In which neighborhood do you live?" **Table 1** illustrates the means (*SDs*) of these variables by experimental condition.

Results

Manipulations Checks

We first examined, whether the four experimental conditions differed in terms of (a) the perceived importance of the information given and (b) the perceived similarity between the

TABLE 1 | Mean scores (SDs) of the ancillary variables by Type of Feedback.

	Social feedback			
	Unidentified		Identified	
	In-group (n = 69)	Out-group (n = 70)	In-group (n = 69)	Out-group (n = 69)
Mean (*SD*) perceived importance of the information (0–6 scale)	3.23 (1.68)	3.06 (1.37)	3.04 (1.53)	2.67 (1.65)
Mean (*SD*) perceived similarity between participants apartment and the referent apartment (0–6 scale)	2.65 (1.50)	2.73 (1.46)	3.04 (1.33)	3.00 (1.32)
Mean (*SD*) number of people living in the participants' apartment including the participant	2.62 (1.35)	3.31 (1.65)	2.96 (1.34)	2.83 (1.21)
Mean (*SD*) participant's actual energy consumption, compared with their neighbors consumption (−3 to +3 scale)	−0.23 (0.99)	0.11 (1.03)	0.16 (1.21)	0.0 (1.07)

participant's household and that described in their information pack (see **Table 1**), and (c) the perceived energy consumption level with respect to other apartments from the participant's neighborhood. We examined each dependent variable by means of a 2 (Social distance: in-group vs. out-group) × 2 (Identification: identified vs. unidentified) between-subjects analysis of variance (ANOVA). The perceived importance of the information did not vary significantly across the conditions (all $ps > 0.12$). Overall, the participants considered the description of the household as quite important, with many answers concentrated on the central value of the 0–6 scale ($M = 3$, $SD = 1.57$). The perceived similarity varied significantly across experimental conditions: Participants rated themselves as marginally more similar to the people described in the identified conditions than to those mentioned in the unidentified conditions ($M_{\text{Identified}} = 3.02$ vs. $M_{\text{Unidentified}} = 2.69$), $F_{(1, 273)} = 3.84$, $p = 0.051$, $\eta_p{}^2 = 0.01$. No differences were found among the experimental conditions in terms of the perceived energy consumption level of the participant's apartment with respect to other apartments from their neighborhood.

Finally, we controlled some further aspects of our experimental manipulation. Firstly, we checked whether our description of a three-student apartment was a realistic reference point by asking how many people live in the actual apartment of the participants. It was. The mean number of persons living in the participants' apartments was very close to 3 ($M = 2.94$; $SD = 1.40$). Secondly, we controlled where the participants lived. None lived in Haifa, and so the Out-group referent was correctly named "out-group."

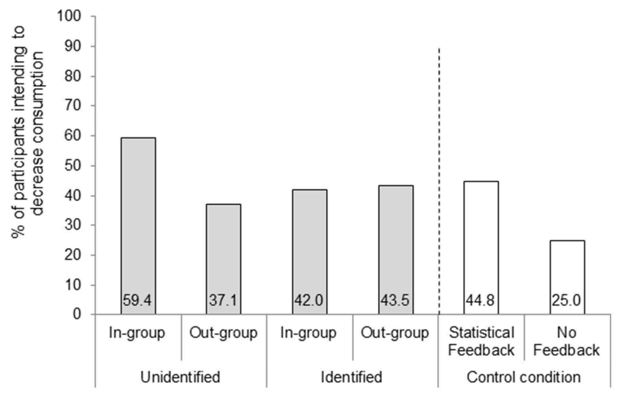

FIGURE 2 | Percentage of participants intending to decrease energy consumption by condition. The number of participants in each group were as follows: In-Group Unidentified (n = 69), Out-Group Unidentified (n = 70), In-Group Identified (n = 69), Out-group Identified (n = 69), Statistical Feedback (n = 29), and No Feedback (n = 28).

Self-rated Intention to Modify Consumption: Choice

We then turned to the participants' energy consumption choices. A preliminary inspection revealed that all participants selected to either decrease or leave unmodified their current energy consumption—no one decided to increase it (option 1). We thus coded their choices by means of a binary variable: decrease consumption vs. consume at current level. The results are illustrated in **Figure 2**.

We ran a logistic regression on the resulting variable using the following factors of interest: Social distance (in-group vs. out-group), Identification (identified vs. unidentified), and their interaction. But we also entered the following factors: Collection period (first vs. second), Perceived importance of feedback, Perceived similarity between participants' own household and referent household, Number of people in the participant's household, and Participant's perception of how their energy consumption really compares to that of their neighbors.

We first focused on the main variables of interest: Social distance, Identification, and their interaction. Social distance exerted an influence, Wald(1) = 6.34, $p = 0.012$, $\beta = -1.08$, Nagelkerke's $R^2 = 0.015$. Overall, a greater percentage of participants stated that they would reduce their energy consumption level when the referent was in-group (50.7%) than when it was out-group (40.3%). Identification also exerted an influence, Wald(1) = 3.84, $p = 0.050$, $\beta = -0.85$, Nagelkerke's $R^2 = 0.004$. Overall, a greater percentage of participants stated that they would reduce their energy consumption level when the referent was unidentified (48.2%) than when it was identified (42.8%). These main effects were qualified by a significant interaction, Wald(1) = 7.1, $p = 0.008$, $\beta = 1.63$, Nagelkerke's $R^2 = 0.018$. These effects were carried by the very large influence that the In-group—Unidentified condition had in decreasing energy consumption (about 60%) vs. the other groups (all close to 40%), as shown in **Figure 2**.

Turning to the remaining factors, only the rated importance of the information had a statistically significant influence: Wald(1) = 51.7, $p < 0.001$, $\beta = 1.0$, Nagelkerke's $R^2 = 0.381$. Perhaps unsurprisingly, the more participants perceived the feedback as relevant, the more they intended to decrease their energy consumption.

Self-rated Intention to Modify Consumption: Amount

We then focused on the percentage by which the participants intended to decrease their energy consumption (for the participants who selected to leave their consumption level unmodified, we inserted zeros). Dovetailing with the results from choice, the condition in which participants were willing to decrease consumption by the greatest amount was the In-group—Unidentified ($M = 7.17\%$). We analyzed the data using a 2 (Social Distance) × 2 (Identification) ANOVA, and we included as covariates the four factors used in the previous analysis. There was no main effect of Social distance [$F_{(1, 268)} = 0.23$, $p = 0.632$, $\eta_p{}^2 = 0.001$] or Identification [$F_{(1, 268)} = 0.15$, $p = 0.697$, $\eta_p{}^2 = 0.001$]. However, once again, we found a significant interaction, $F_{(1, 268)} = 8.31$, $p = 0.004$, $\eta_p{}^2 = 0.03$. As was the case with choice, the only covariate that had a statistically significant influence was the perceived importance of the feedback, $F_{(1, 268)} = 61.51$, $p < 0.001$, $\eta_p{}^2 = 0.19$. These results are described in **Figure 4**.

Inspection of the data revealed that participants anchored their judgments on the suggested 10% decrease. Out of all participants stating that they intend to decrease their energy consumption, the majority (54%) intended to decrease it by exactly 10%. We will return to this finding in the General Discussion.

Self-rated Intention to Modify Consumption: Saving Strategies

A subset of the participants ($N = 118$) indicated the three ways by which they intended to save energy. The results are illustrated in **Figure 3**. The most chosen option was "Turn off the light when you exit the room" (31%), while the second and third most chosen options were "Turn off your computer and monitor when not in use" (22%) and "Wash only full loads of dishes and clothes" (22%). These data indicate that there is a certain degree of consistency across participants in their preferences about how to save energy.

Summary

We examined whether the effect of comparative feedback (a typical household consumes 10% less) on self-rated intentions to modify energy consumption is moderated by information concerning the "typical household": whether it is located in the same vs. a different neighborhood, and whether its members are identified by names, age, and a photograph vs. they remain unidentified. It was, but not in the way we had anticipated. The most successful intervention was the one where the referent household was from the same neighborhood and its members were unidentified (In-group—Unidentified).

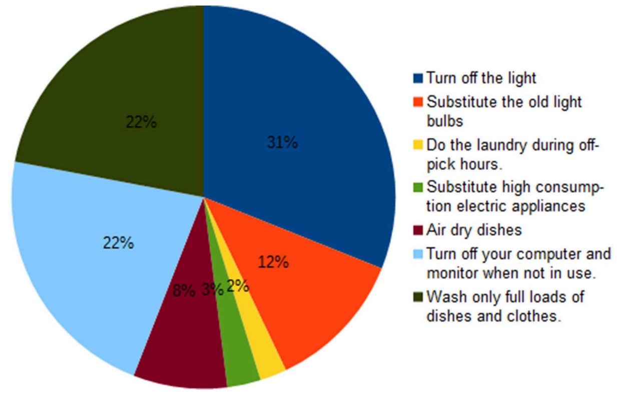

FIGURE 3 | A pie chart indicating the percentage of times that a saving strategy was chosen.

Control Conditions

The analyses presented above lack a suitable control condition, a baseline. Theoretically, the self-rated intention to decrease energy consumption might be even higher if no feedback or just statistical feedback is given. To examine these possibilities, during the second collection period we gathered data from two control conditions: Statistical Feedback and No Feedback. Participants in the Statistical Feedback condition were informed that: "Your energy consumption exceeded the average household consumption level by 10%." Participants in the No Feedback condition received no information about others' energy consumption levels. Subsequently, participants were asked to decide whether they intended to increase, keep constant, or decrease their energy consumption level (as in the experimental conditions, no one chose to increase energy consumption). In case they decided to change their consumption level, they had to indicate by how much (%). Because the control conditions offered no information or very abstract information about a referent household, we did not collect perceived similarity ratings between the participants' household and the referent household, or importance ratings of the feedback. Below, we compare the findings of the four experimental conditions to those of the control conditions.

Results

Self-rated Intention to Modify Consumption: Choice

First, we compared the six conditions with a logistic regression, specifying the No Feedback condition as the baseline condition. In essence, this analysis examines the extent to which providing comparative feedback (social or statistical) promotes energy saving. As anticipated, feedback influenced the decision to save

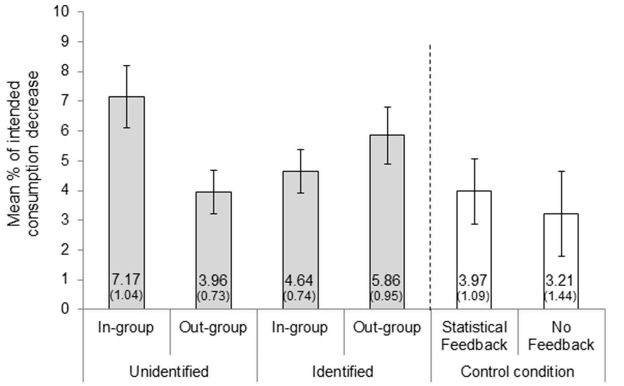

FIGURE 4 | Mean (SE) amount of intended consumption decrease by condition. Error bars indicate the standard error of the mean. The number of participants in each group were as follows: In-Group Unidentified (n = 69), Out-Group Unidentified (n = 70), In-Group Identified (n = 69), Out-group Identified (n = 69), Statistical Feedback (n = 29), and No Feedback (n = 28).

energy Wald(5) = 11.76, $p = 0.038$, Nagelkerke's $R^2 = 0.49$. Overall, a higher percentage of participants chose to reduce their energy consumption in the Feedback conditions than in the No Feedback condition. However, out of the five comparisons, only the comparison between the In-group—Unidentified condition ($M = 59.4\%$) and the No Feedback condition ($M = 25\%$) was statistically significant [χ^2 (1, $N = 97$) = 9.44; $p = 0.002$, $\varphi = 0.31$].

Subsequently, we tested whether the In-group—Unidentified condition was more effective than all the other feedback conditions. To this end, we compared it against a pooled condition that includes all other feedback conditions (for a similar analysis, see Goldstein et al., 2008, Exp. 2). It was (59.4% vs. 41.4%), χ^2 (1, $N = 306$) = 7.04; $p = 0.008$, $\varphi = 0.15$. The results about choices are illustrated in **Figure 2**.

Self-rated Intention to Modify Consumption: Amount

Analyses of the specific amount by which participants were intending to decrease energy consumption, provided similar results (see **Figure 4**). We analyzed these data by means of a One-Way ANOVA. The mean amount of energy saving was influenced by condition, $F_{(5, 328)} = 2.24$, $p = 0.050$, $\eta_p{}^2 = 0.03$, with the In-group—Unidentified condition registering the highest amount of intended saving ($M = 7.17\%$) and the No Feedback condition the lowest ($M = 3.21\%$). Furthermore, participants in the In-group—Unidentified condition planned a significantly higher amount of intended saving ($M = 7.17\%$) than all the other feedback conditions pooled together ($M = 4.71\%$), $t_{(304)} = -2.52$; $p = 0.012$, Cohen's $d = 0.32$.

Summary

As anticipated, providing feedback (either social or statistical) vs. not providing feedback increased both the percentage of choices to decrease energy consumption, as well as the amount of planned energy saving. Furthermore, from all types of feedback, the one concerning the In-group—Unidentified household promoted the highest energy consumption savings.

General Discussion

Findings in social psychology research have been used to create nudging techniques (Thaler and Sunstein, 2008). An effective technique to save energy is providing social feedback about *what* comparable others do (e.g., Goldstein et al., 2008). Here, we asked whether we could further sharpen this nudge. Building on research on the identified victim effect (e.g., Small and Loewenstein, 2003) we manipulated *who* the comparable others are on two dimensions: whether they came from the same vs. a different group, and whether they were identified vs. unidentified. We also included two control groups: a statistical feedback group and a no feedback group. In line with previous research, we found that feedback (vs. no feedback) increased both the intention to diminish energy consumption and the amount of consumption decrease. Importantly, one particular type of comparative feedback, the one concerning a household from the same neighborhood (in-group) but with no identifying details (unidentified), was the most effective.

This result is surprising. Most previous research suggests that people are more willing to help identified rather than unidentified individuals from one's in-group (e.g., Small and Loewenstein, 2003; Kogut and Ritov, 2005a,b; Slovic, 2007; see Introduction). However, recent studies have shown that under certain conditions this preference may reverse. One such case is when one's group is perceived as particularly homogeneous or cohesive (it has a high degree of "we-ness"; Bollen and Hoyle, 1990). In such circumstances, an individual might identify more with a generic group member than with an identified group member (see also Turner et al., 1987). For example, Ritov and Kogut (under review), (Study 2) conducted a second dictator game study. As in their Study 1, before playing the game participants were assigned into two groups supposedly on the basis of their artistic preferences. However, in Study 2 participants played a group game before playing the dictator game, in which they had to identify (as a group) as many characters as possible in a big poster. The purpose of this game was to increase group cohesiveness. Contrary to Study 1, in Study 2 "dictators" allocated significantly more money to in-group unidentified members (5.4 shekels) than to in-group identified members (3.8 shekels).

Returning to the present study, it could be that Israeli students perceived households from their neighborhood to be a highly cohesive category. One reason to expect this, is that the target city, Jerusalem, includes very diverse neighborhoods. For example, the Old City is roughly divided in the Jewish, Christian, Muslim, and Armenian Quarters. Research has shown that inter-group conflict increases the perception of cohesiveness with one's in-group (Ritov and Kogut, 2011). In a highly cohesive category, members of the category may perceive an unidentified, prototypical in-group member as more similar to themselves than an identified individual member. The effect of cohesiveness on perceived psychological distance may thus be at the source of the observed reversal of other-identifiability effect.

Another explanation for the reversal of the other-identifiability effect concerns the information provided in the identified condition, and specifically the photograph (see **Figure 1**). Participants might have found it curious that the energy company sent them a letter with a picture and names of other consumers (in other experimental contexts, such as donations, providing such details is unsurprising). Other forms of manipulations might have been more natural in the present experimental context. Our decision to use pictures and detailed descriptions was aimed at maximizing the emotional vividness of the identified conditions. However, future research could manipulate identifiability through other means.

Interestingly, if we consider all groups where feedback was provided, the majority of participants (53%) who decided to decrease their energy consumption opted for a 10% reduction, the exact amount required to match the norm. Although inferences from intentions to behaviors call for cautiousness (e.g., see Sheeran, 2002), previous field research has shown that comparative feedback makes participants change their actual consumption level (up or down) in the direction of the norm (e.g., Schultz et al., 2007). So, if intentions translate to behaviors, and if people have some sense of what it means to modify their energy consumption by a given amount, this could provide further means to nudge people toward energy savings.

The present findings carry potential benefits for various stakeholders. If such interventions prove successful, households could save money[2]. At a governmental level, a state that reduces energy consumption depends less from foreign energy supply, which in turn has strong economic and political advantages. Finally, a reduction in energy consumption can improve the well-being of future generations: saving energy implies a lower consumption of non-renewable resources (e.g., oil, coal) and a less polluted environment. At a policy level, nudge strategies utilizing comparative feedback are one of the several instruments that the national authorities have to increase energy efficiency. From a legal perspective, consumers have the right to have easy access to information about their actual consumption levels but also to complementary information, which refers "to the past consumption of an average final consumer or a target consumer belonging to the same category" [European Parliament and Council, 2012; Art.9, paragraph 7(e), Legislative Decree, July 4 2014, n. 102]. The aim of the Legislator is to facilitate such comparative evaluations for the final consumer. But, which is the optimal level of description to achieve this? This is not an easy question to answer. Previous studies (Kahneman et al., 1999; Bonini et al., 2008) show that, several elements influence how people categorize and interpret information during a comparative evaluation. Coherently with those results, the present findings suggest that subtle differences in the way the comparative consumer is described might yield strong differences in the willingness to reduce energy consumption.

As denoted by the subheading of our article, "A preliminary study," the present findings should be considered as a starting point. Their generalizability is limited for two reasons. First, they were based on Israeli university students. Future research could focus on different types of residential consumers, and from diverse geographical areas. This is important because research suggests not only that there are differences in energy consumption behaviors between cultures (Wilhite et al., 1996), but also within a given culture. For example, a recent study by Costa and Kahn (2013) on the influence of descriptive norms showed that, energy saving interventions in the US were more effective with registered liberals than with registered conservatives. Future studies, for example, could examine variables such as political orientation, and wealth. Second, the current study measured the intention to modify energy consumption rather than actual behavior. Ultimately, the effectiveness of the suggested intervention should be assessed by field studies.

In conclusion, we found that in a comparative social feedback it is not only important to know *what* others do, but also *who* these others are. Although, the present findings are preliminary, if supported, they would suggest a simple, cost-effective nudging technique to reduce people's energy consumption levels. Future studies should also investigate whether the In-group—Unidentified condition would always promote the highest compliance rate. We surmise that in certain cases, such as when group cohesiveness or homogeneity is low, social comparison with an In-group—Identified member might prove more efficient.

Acknowledgments

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01287

[2]Data from the World Energy Council (2014) indicate that the per household residential electricity consumption in Israel in 2013 was about 6400 kWh, with a price of.15 US dollar/kWh. These figures, applied to our findings, would translate in the following annual saving: $69 for the most successful intervention (in-group unidentified), compared to $45 for the other feedback conditions pooled together. These estimates, which should be used with caution, give a general idea of the potential economic impact of these *nudge* strategies.

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Talking with consumers about energy reductions: recommendations from a motivational interviewing perspective

Florian E. Klonek * *and Simone Kauffeld*

Department of Industrial/Organizational and Social Psychology, Technische Universität Braunschweig, Braunschweig, Germany

Reduction of energy costs has become a concern for many organizations. First, we review energy-saving studies in organizations in which consumers showed resistance to change their behavior. Second, we relate resistance to change to the psycholinguistic construct "sustain talk" that describes verbal arguments against behavior change (e.g., "Work processes have priority here"). Third, we argue how Motivational Interviewing (MI)—an interaction-approach to facilitate behavior change—might be helpful in dealing with this behavior. We transfer MI to interactions about energy-savings in organizations and demonstrate how qualification in MI for energy managers may affect these interactions. Therefore, we present three short case scenarios (i.e., video vignettes) that demonstrate socio-interactional mechanisms underlying energy-relevant decisions and behaviors. Consumer' verbal responses are graphed as one single time-variant index of readiness versus resistance (R-index) in order to illustrate interactional dynamics. In sum, we combine theoretical and empirical perspectives from multiple disciplines and discuss an innovative socio-interaction approach that may facilitate energy-efficient behavior in organizations.

Keywords: change intervention, change talk, energy-saving, interaction analysis, motivational interviewing, MI Skill Code, resistance to change, R-index

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Tobias Brosch, University of Geneva, Switzerland

Reviewed by:
Wing-Yee Cheung, University of Southampton, UK
Lisa Glynn, Veterans Affairs Puget Sound Health Care System, USA

Correspondence:
Florian E. Klonek, Department of Industrial/Organizational and Social Psychology, Institute of Psychology, Technische Universität Braunschweig, Spielmannstr. 11, 38106 Braunschweig, Germany
f.klonek@tu-bs.de

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Reducing the impact of rising energy costs has increasingly become a concern for many organizations (Garabuau-Moussaoui, 2014; Leyge, 2014; Morgenstern, 2014; Tharan, 2014). Whereas the engineering field has developed mostly technical measures to increase energy efficiency, there is an increasing trend to recognize that the behavior of consumers who actually work in the organizations is equally important (Kraft and Neubeck, 2004; Carrico and Riemer, 2011; Janda, 2011; Steiner et al., 2011; Kauran, 2013; Cowan, 2014; Parkes, 2014; Schäfer, 2014). However, recent studies that aim to reduce energy behavior have also reported that consumers show resistance to changing their energy consumption at work (Griesel, 2004; Kaplowitz et al., 2012; Murtagh et al., 2013).

In order to facilitate interactions with consumers about energy-relevant decisions, this perspective paper offers the following contributions. First, we give a brief overview of organizational studies that reported consumer resistance when energy-relevant behaviors were in need of change. Second, we relate resistance to change to the psycholinguistic constructs of change language (i.e., change talk vs. sustain talk) and hypothesize that language is an active ingredient in fostering behavior change. Third, we propose Motivational Interviewing (MI) to be a social interaction-based approach that may help energy managers to promote energy-saving behaviors in organizations. We draw on empirical evidence in the field of clinical psychology (e.g., Magill et al., 2014) in order to hypothesize how interactional mechanisms could affect energy-relevant behavior. Fourth, we produced demonstration material that highlights how MI-based approaches could be applied in the context of energy-saving interventions. Fifth, we visualize interactional dynamics with a newly developed temporal measure of readiness and resistance to change by means of three video vignettes. Human resources and training departments in organizations can use these vignettes for training purposes.

Behavior-Based Energy-Saving Interventions and Resistance to Change

Organizations are increasingly trying to save energy either for economic purposes or to accomplish a reduction of carbon emissions (Homburg, 2004; D'Mello et al., 2011; DuBois et al., 2013). Whereas one energy-efficiency approach includes technical improvements, such as increased heat insulation or replacing ventilation with volume flows (Lutzenhiser, 1993), technical engineers are realizing that the behavior of people who work in organizations also contributes to energy consumptions (Janda, 2011). Science laboratories in universities have one of the highest energy usages and offer high potential to implement behavior-based energy-conservation procedures with consumers (Kaplowitz et al., 2012). Kaplowitz et al. interviewed 59 participants (principal investigators, lab staff, and student researchers) about possibilities to adapt energy-conserving behavior at work. Despite a favorable attitude toward energy-saving behaviors, participants argued that operational, economic, and work-related barriers hindered them from saving energy. In a study from Griesel (2004), the author conducted a workshop with university staff to promote energy-efficient behavior. She reported that some of the proposed measures (e.g., switching off laptop computers during breaks) were considered unacceptable by participants.

Murtagh et al. (2013) reported similar problems in an energy-saving intervention study. The authors implemented a monitoring device in a university office building that displayed employees their current energy use. Unfortunately, 41% of the participants did not even register for the feedback device. The authors also held focus groups about their office energy use and reported that participants showed a "syndrome of reasoning" (Murtagh et al., 2013, p. 724)—a term for describing verbal responses or self-defense for not saving energy (e.g., inconvenience, technical reasons/myths, social norms, automation, work demands, savings are too small, etc…).

Altogether, observations from these organizational studies suggest that the language of consumers seems to be indicative of their respective motivation. Participants who are not motivated to take further actions will also express this verbally. In fact, verbal behavior ("I will not do this") is a powerful means to express resistance toward change measures (Klonek et al., 2014). More recent methodological work has proposed measuring participants' readiness or resistance[1] in interactions about behavior change in terms of change talk versus sustain talk (Moyers et al., 2007; Miller and Johnson, 2008; Gaume et al., 2010; Magill et al., 2010; Klonek et al., 2014; Lombardi et al., 2014; Paulsen et al., 2015). Change talk includes statements that express consumers' readiness to adopt energy-saving routines, such as reasons ("Energy waste is related to increased department costs"), desires ("We do not want to waste energy here"), or needs to change ("It is prohibited by security management to open the windows at night"). By contrast, sustain talk comprises language that speaks against energy-saving measures, such as resistance, reasons to sustain the status quo, a lack of abilities ("I do not know how to operate the heating system—therefore, I don't change it"), or lack of commitment ("I won't promise that I will always think about switching off the lights"). Furthermore, change and sustain talk can be regarded as driving and hindering forces that may determine consumers' energy-related behaviors (Klonek et al., under revision).

This language-based view takes into account that consumers usually express ambivalence rather than sole resistance toward change measures ("Yes, energy savings are important, *but* it impedes my work flow to shut down the computer during breaks"; Piderit, 2000; Arkowitz, 2002; Klonek et al., 2014). In this view, one part of the statement argues in favor of change, whereas the other part argues against change. These conflicting values are like opposite sides of a decisional balance (Janis and Mann, 1977; Klonek et al., under revision) that are dynamically tipping from one side (sustaining behavior) to the other (changing behavior). So what can organizations do in order to increase the weight of the decisional balance so that consumers move toward saving energy?

One social interaction-based approach that makes use of an individual's ambivalence toward change is a method called MI. It is a communication-based approach that has received large support by numerous meta-analyses as an evidence-based intervention in the helping professions (Hettema et al., 2005; Rubak et al., 2005; Lundahl et al., 2010; Magill et al., 2014). We will briefly present the basic tenets of MI and argue how energy managers in organizations could benefit from MI training.

What is Motivational Interviewing and how Might it Improve Interactions about Energy Behavior?

MI can be considered as a social interaction-based approach that combines a humanistic mindset with verbal micro-techniques. Technically, it is defined as a

> "collaborative, goal-oriented style of communication with particular attention to the language of change. It is designed to strengthen personal motivation for and commitment to a specific goal by eliciting and exploring the person's own reasons for change within an atmosphere of acceptance and compassion." (Miller and Rollnick, 2013, p. 29).

[1]Please note that the terms resistance and sustain talk are not interchangeable terms. Typically, current MI theory distinguishes between resistance and sustain talk. Resistance is "interpersonal behavior that reflects dissonance in the working relationship [whereas] *sustain talk* does not in itself constitute discord" (Miller and Rollnick, 2013, p. 408). Resistance is necessarily interpersonal (i.e., not residing within the person) and specifically different from sustain talk. As organizational researchers are more familiar with the term "resistance to change," we use this term in order to connect it with recent conceptions of socio-interactional dynamics in behavior change.

MI shares some common ground with participatory energy-saving interventions (e.g., consumer-centered formats, such as workshops; Matthies, 2000; Griesel, 2004) and commitment-building strategies (Lokhorst et al., 2013) that have been proposed to be effective in promoting sustainable behavior change. However, MI significantly contributes to these approaches because it gives clear recommendations for how to deal with resistance and how to increase intrinsic motivation. For example, one of the MI principles is to work out discrepancies in a collaborative way: These discrepancies can encompass, for example, energy-wasting behaviors that are at odds with specific values of the consumer (e.g., "economizing resources" or "being a role-model"). An MI approach advocates that energy-saving procedures should not be enforced top-down from the organization, but rather that consumers' intrinsic motivation has to be developed bottom-up. MI also adds a goal-oriented component in the interaction by reinforcing consumers' own argumentation to save energy, in essence, tipping the decisional balance toward a specific target behavior (i.e., saving energy).

Traditionally, MI is taught within the helping professions, for example, among therapists, counselors, physicians, or nurses (Madson et al., 2009; Forsberg et al., 2010; de Roten et al., 2013). More recent studies have provided evidence that MI is also teachable to non-helping professions, e.g., for engineers (Klonek and Kauffeld, in press) or for environmental inspectors (Forsberg et al., 2014). Whereas MI has not been used in organizations in order to reduce energy-related behavior at work, it has great promise of equipping energy managers successfully with the right mindset and verbal skills in order to discuss these matters.

Demonstration of MI: The Energy Manager as a Social Change Agent

In order to showcase the use of MI as a communication method for energy managers, we developed three vignettes (i.e., scripted audio and video material) in which an energy manager discusses energy-efficient behavior with an employee. The development of this material was guided by a multi-step procedure in which we integrated interaction material from two different sources.

First, we used three existing interaction scenarios that systematically varied in terms of MI consistency (Project MILES, 2011)[2]. These scenarios were developed independently from a German MI expert who is also a member of the Motivational Interviewing Network of Trainers (2008). Transcripts were also annotated previously with a coding instrument that classifies verbal behaviors in MI (Martin et al., 2005; Hannöver et al., 2013). As the content of these interactions was not related to energy-saving behavior (i.e., the conversations covered the reduction of smoking behavior), we only used the structure of the behavioral dynamics and replaced the content with arguments that are characteristic of energy-related interactions.

The second source of data included videotaped interactions in which energy advisors discussed energy-reduction measures with consumers in non-residential buildings (cf. Klonek et al., 2014, submitted). These videotapes served to provide typical arguments that are provided within energy-related interactions (e.g., replacement of several refrigerators with a single one).

Material from both sources was combined systematically in an iterative process and resulted in three vignettes about energy reductions at work (see supplementary audio online material, "Audio 1–3" for English conversations; "Audio 4–6" for German conversations). **Table 1** shows the first seven turn takes for each scenario. We kept the content of each conversation similar but varied the interactional dynamics in each conversation in order to illustrate how subtle micro-behaviors may influence the course of an interaction (i.e., the subsequent response of the conversational partner). The mechanisms of interpersonal dynamics were based on theoretical assumptions (i.e., technical hypotheses) and empirical support from MI research (Magill et al., 2014): The main assumption of the technical hypothesis is that MI inconsistent behaviors are positively associated with sustain talk (e.g., Apodaca and Longabaugh, 2009; Klonek et al., 2014) and negatively associated with change talk (e.g., Gaume et al., 2010), whereas MI consistent behaviors make change talk more likely and sustain talk less likely (e.g., Moyers et al., 2007). With respect to conversations about energy-reductions at work, the technical hypothesis implies that energy managers who are trained in MI verbal skills (Energy Manager B; Audio 2 and 4) will likely increase employees change talk. In contrast, energy managers that have not acquired verbal skills in MI (Energy Manager C; Audio 3 and 6) will also use more MI inconsistent behaviors in conversations to reduce energy and therewith decrease change talk and/or increase sustain talk, respectively.

A Closer Look at Verbal Sequences in Energy-Related Consumer Interactions with the MI Skill Code

In a second step, we used the MI Skill Code (MISC; Miller et al., 2008) in order to shed light on the interactional dynamics of these conversations. The MISC is an observational coding instrument to assess MI specific verbal skills (for the German version, MISC-d[3]: Klonek and Kauffeld, 2012). It defines three behavioral macro-categories for interviewer behaviors (i.e., energy manager) that are either consistent, inconsistent, or neutral to an MI approach. Along the same line, the MISC also defines three macro-categories for the interaction partner (i.e., consumer) that describe their verbal response in terms of change talk, sustain talk, or follow neutral (i.e., no relation to the change topic). Finally, all behavioral macro-categories can be classified into more fine-grained behaviors: For example, open questions, affirmations, emphasizing control, or giving support are all consistent with MI, whereas warnings and confrontations are inconsistent with MI (a full overview of all 34 codes of the MISC is given

[2]http://www.medizin.uni-greifswald.de/medpsych/index.php?id=453$

[3]The MISC-d also includes information on software-support, observer training material, data checking-routines, and use of neutral terms for interaction partners to make the instrument transferable to energy-saving conversations.

TABLE 1 | Comparison of the first seven turn-takes from the three demonstration interactions about energy-saving behavior at work (fully coded transcripts of all scenarios are provided as online material).

Event	Speaker	Scenario A–C		
		Energy manager A	**Energy manager B**	**Energy manager C**
1	Energy manager	Today, I would like to talk with you about possibilities to save energy. [Structure]		
2	Employee	Okay. [Follow Neutral]		
3	Energy manager	You work in a laboratory. There are some options that will certainly allow you to save energy. [Giving Information]		
4	Employee	[I not only work in a laboratory, but I also work in an office.] [Follow Neutral] [There are certainly some options to save energy.] [Change Talk-Other] [These so-called "options" are always connected to large expenditures.] [Sustain Talk-Reason]	[I not only work in a laboratory, but I also work in an office.] [Follow Neutral] [There are certainly some options to save energy.] [Change Talk-Other] [However, these so-called "options" are always connected to large expenditures.] [Sustain Talk-Reason]	[I not only work in a laboratory, but I also work in an office.] [Follow Neutral] [These so-called "options" are always connected to large expenditures.] [Sustain Talk-Reason]
5	Energy manager	**Don't be so rash**. [Confrontation] First off, we should speak about the methods you already use to save energy. [Structure] **Can you think of some?" [Closed Question]**	First we should perhaps talk about where you already save energy. [Structure] **What do you do already to save enery? [Open Question]**	**Don't be so rash**. [Confrontation] First off, we should speak about the methods you already use to save energy. [Structure] **Can you think of some? [Closed Question]**
6	Employee	[Well, for example, I have set up my PC with a coupler strip so that it is not running on standby the entire time.] [Change Talk-Taking Steps] [But if I am in a hurry in the evenings, I don't always remember to do this.] [Sustain Talk-Taking Steps]	[Well, I always turn on my PC using a coupler strip so that it is not always running on standby.] [Change Talk-Taking Steps] [But in the evenings if I am rushed before quitting time, I don't always do this.] [Sustain Talk-Taking Steps]	[Well, for example, I have set up my PC with a coupler strip so that it is not running on standby the entire time.] [Change Talk-Taking Steps] [But if I am in a hurry in the evenings, I don't always remember to do this.] [Sustain Talk-Taking Steps]
7	Energy manager	So it's not so important to you to save energy in this way. I mean, it is a hand movement - then the switch is turned off. [Confrontation]	**So often in the past you have switched the PC completely off, so that it does not run on Standby. Occasionally, though, you are in too much of a hurry and this is not consistently done.** [Complex Reflection]	So it's not so important to you to save energy in this way. I mean, it is merely a hand movement - then the switch is turned off. **That is really no big deal!** [Confrontation]

Bold = highlights important differences in verbal behavior of the energy manager.

in the manuals). Altogether, the MISC can be used for annotating conversational dynamics for process researchers (e.g., Moyers et al., 2007). We coded the verbal behaviors between the energy manager and the employee (all coded transcripts, i.e., the Energy Manager A–C, are provided as supplementary online material; "Data Sheet 1–3" for English transcripts; "Data Sheet 4–6" for German transcripts). **Table 1** shows the MISC codings for the first seven speaker turns in each scenario. It aims to illustrate how subtle micro-changes within a conversation could influence the motivational response of the conversational partner.

The energy managers start to differ in their verbal behavior in the fifth event of each scenario (cf. **Table 1**). For example, energy manager B uses an open question instead of a closed question. The assumption in MI is that open questions are person-centered verbal techniques that invite the interaction partner to disclose more information. In this case, the manager asked the employee about her past behaviors to save energy. The question is evocative because it stimulates the employee to discover potential discrepancies between behaviors at home vs. at work.

In the seventh event, the manager in scenario B uses a complex reflection—MI consistent behavior—whereas the managers in scenarios A and C confront the employee. Confrontations are MI inconsistent "expert-like responses that have a particular negative-parent quality" (Miller et al., 2008, p. 11). They restrict the autonomy of the employee and can even arouse reactance (Klonek et al., 2014). By contrast, complex reflections are person-centered techniques that repeat or paraphrase statements of the employee, but can also add meaning to it. Reflections are active listening statements in which the energy manager tries to understand the problems of the employee in implementing energy-saving routines. This can positively influence the relationship between conversational partners. Furthermore, reflections help the conversational partner to listen to their own statements (i.e., reflecting as a form of verbal mirroring) and selectively stress their change talk to direct the interaction toward the change target (Barnett et al., 2014).

Capturing Change-Related Dynamics with Consumers: The R-Index

In the previous section, we have described some micro-interactional dynamics using the MISC (e.g., MI inconsistent

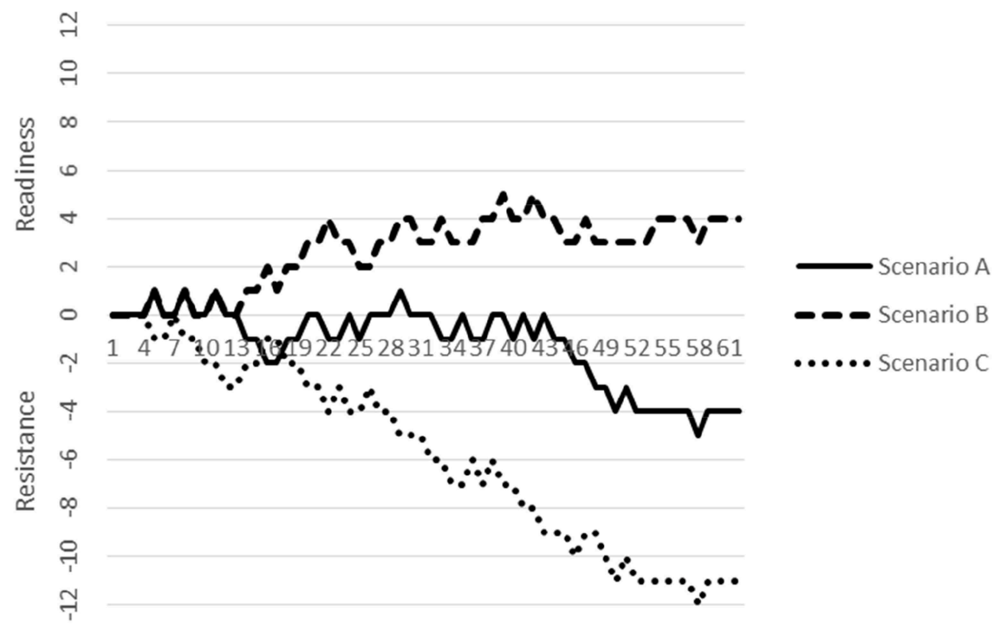

FIGURE 1 | Interactional dynamics graphed with the R-index (Readiness/Resistance) for the three demonstration scenarios on energy-saving behavior at work. *Note*. The x-axis shows the number of events (i.e., parsed thought units or utterances).

behavior, followed by sustain talk). Whereas this perspective helps energy managers to reflect on their verbal behaviors, we also want to show how to capture the readiness of consumers on a broader interaction scale. As noted above, the MISC defines verbal responses of conversational partners in terms of change talk, sustain talk, and follow neutral. Recent MI process research suggests using composite scores of change and sustain talk as a "single measure of motivational balance" (Magill et al., 2014, p. 7). Therefore, we developed a mathematical function that transforms these verbal codes into a single-index of readiness and resistance: The R-index (a full description is given in Klonek et al., under revision). Basically, change talk is transformed into a positive integer (+1), whereas sustain talk is transformed into a negative integer (−1), and follow neutral is transformed into zero (0). As the verbal behavior of the conversational partner unfolds over time, it creates a repeated measurement of change talk (+1) and sustain talk (−1) utterances. One of the basic idea in MI is that conversational partners can talk themselves into the target behavior (e.g., saving energy) by increasing their own change talk. Therefore, the sequence of verbal responses is cumulated from the beginning until the end of the interaction. This summation results in a time-variant index that can show readiness to change (positive slope) versus resistance to change (negative slope). We have produced R-curves for all three vignettes (A–C) as an interactive video demonstration (see video material in the supplementary online material, "Video 1–3" for English videos; "Video 4–6" for German videos). **Figure 1** depicts how the readiness of the employee increases stepwise in scenario B. As noted above, energy manager B used verbal techniques that are characteristic for MI. By contrast, the R-index in scenario C indicates strong employee resistance. Equally, energy manager C showed behaviors that are inconsistent with an MI approach, such as confronting, blaming, and restricting autonomy of the employee. In scenario A, the R-index fluctuates between positive and negative values, that is, the employee showed ambivalence toward change. In this scenario, energy manager A showed both MI consistent and inconsistent behaviors.

All vignettes (coded transcripts, audio files, and videos showing the R-index) can be used for sensitizing practitioners for interactional dynamics in energy-related conversations or as MI training material. Furthermore, future studies can use this training material to investigate whether MI can help organizations to reduce energy consumption in organizations.

Conclusion

The current perspective integrated the expertise of different disciplines, that is, clinical psychology, change management, communications, and behavioral sciences. We presented a MI-based socio-interactional approach that may positively influence energy-relevant decisions in organizations by means of its person-centered and directive approach. By creating role-played vignettes based on recent empirical meta-analyses about MI in clinical process studies (Magill et al., 2014), we illustrated how MI-consistent and MI-inconsistent employer behaviors could theoretically affect consumer responses in the context of energy-related behavior change discussions. We introduced an observational coding scheme (the MI Skill Code) as a means to investigate behavior change interactions. Finally, we created video vignettes of the coded material in which we summarized the complex coding system into one single index of consumer readiness within an energy-related conversation. This material can be used for sensitizing energy managers and change agents for interpersonal dynamics in behavior change and for future energy-saving studies that aim to use MI.

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Supplementary Material

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The Role of Energy Visualization in Addressing Energy Use: Insights from the eViz Project

Sabine Pahl[1], Julie Goodhew[1], Christine Boomsma[1] and Stephen R. J. Sheppard[2]*

[1] School of Psychology, Plymouth University, Plymouth, UK, [2] Collaborative for Advanced Landscape Planning, University of British Columbia, Vancouver, BC, Canada

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Energy has become an important topic for policy makers, industry, and householders globally (e.g., IEA-International Energy Agency, 2015). Changing the way we generate and use energy could make a huge contribution to reducing carbon emissions and help address climate change. There is also concern over energy security where energy is imported from other countries. Fluctuations in energy prices affect industry and householders and are linked to fuel poverty, especially in vulnerable households (Liddell and Morris, 2010).

Increasing energy efficiency has been hailed as a key solution to dealing with the energy issue (see www.eceee.org) but has perhaps not received as much attention as is warranted by its huge potential. This may be because energy efficiency is not one specific solution; rather many small changes and interrelated steps are required. This is contrary to big-ticket visions such as finding a novel non-carbon source of energy or other solely technological solutions, ranging from renewed investment in nuclear power to automating energy processes in buildings.

Thus, there seems to be a degree of conflict between focusing on technology, automation etc. and a more systems-focused approach that includes social factors such as people's attitudes, values, and behaviors. We think the way forward is to integrate technical and social approaches, especially where they intervene in people's daily lives. It is necessary and important to communicate and discuss energy issues with the wider public in order to find acceptable, effective and sustainable solutions, whether these are grid-related or about specific buildings. For example, building science colleagues have often complained (jokingly or not) how occupants are "messing up" after key energy-saving technology has been implemented in home or work contexts (e.g., see literature around the energy performance gap). Moreover, recent work has highlighted the phenomenon of techno-optimism whereby people tend to overestimate the success of new technologies (Clark et al., 2015). These wider considerations serve to situate our eViz project (eViz.org.uk) from the point of view of social scientists working on an issue traditionally dominated by "technical" experts and views.

Having said this, the energy field is burgeoning with new initiatives (e.g., new journal Energy Research and Social Science) and explicitly social science-led research projects (e.g., www.projectcharm.info/; www.eviz.org.uk; http://c-tech.cloudapp.net/). At the global level, the IEA is funding work on behavior change (www.ieadsm.org/ViewTask.aspx?ID=16&Task=24&Sort=0) and occupant behavior (annex66.org/) although the latter group is still dominated by technical experts. The debate around technical, social and integrated solutions leads to the question of how best to communicate the energy use embedded in people's everyday actions and familiar surroundings, with the ultimate aim of engaging consumers and change behavior. The traditionally hidden nature of energy has been observed as one barrier to energy awareness, and making energy information accessible is suggested to empower people (Darby, 2001; Parnell and Popovic Larsen, 2005). In line with this are vigorous calls for making energy visible, including several nations' commitments to add energy displays to every home.

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Edited by:
Tobias Brosch, University of Geneva, Switzerland

Reviewed by:
Kathryn Emma Buchanan, University of Essex, UK

****Correspondence:***
Sabine Pahl
sabine.pahl@plymouth.ac.uk

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The present paper reports on work from our ongoing eViz project focusing on energy visualization. At the time of writing we are in the final year of this 3.5 year project that integrates researchers from psychology, building science, data visualization, and computing. We investigate how to reduce energy demand in buildings by transforming people's understanding and behavior through energy visualization. The Psychology literature suggests energy visualization is crucial for at least four reasons.

First, making the invisible visible attracts people's attention (Gardner and Stern, 2002). Attention is important when communicating any topic to the public, but especially in the current context as energy use tends not to be people's primary goal in day-to-day life. Visual imagery has the ability to communicate messages quickly and powerfully and enables the conceptualisation of complex issues (Sheppard, 2001, 2005). Second, there is a strong link between emotions and visual images. Basic emotions evolved relatively early, before the development of higher level conscious processes such as language. As a result, emotions are more dependent on and respond quicker to information in visual, rather than textual, form (Holmes and Mathews, 2010). Third, taking together the ability of images to grab attention and evoke emotions, images can be described as "vivid" representations (Nisbett and Ross, 1980). Vivid information is linked to a greater "imageability" (Taylor and Thompson, 1982) and the generation of mental images. These mental representations that take the form of sensory images (Slovic et al., 1998; Andrade et al., 2012) are easily retrieved and facilitate the processing of the message (Smith and Shaffer, 2000). So, visual information can be internalized in the form of mental images which aid memory. Fourth, research in cognitive psychology has indicated that mental images have an important motivational role through their link with goals (cf. Kavanagh et al., 2005). Mental images connect to emotions and trigger related goals after being activated through internal or external cues. Further, new goals might be formed by generating new mental images (Conway et al., 2004). In sum, according to psychology research, images attract attention, evoke emotions, facilitate memory, and trigger (the development of) goals (see illustration in **Figure 1**). Furthermore, through these properties, images may support social processes and aid collective action by serving as a shared catalyst and reinforcement between energy users.

How can we apply these principles to the field of energy? There are different ways of visualizing energy. Energy displays in the home are one example but are they sufficiently attention-attracting, memorable, emotional, and meaningful? Buchanan et al. (2014) raise critical views on the ability of basic energy displays to engage consumers meaningfully and over long periods of time (see also Hargreaves et al., 2010). For the purpose of the present paper we will focus on research surrounding one specific tool: thermal imaging (see example in **Figure 1**).

Thermal images provide a visualization of heat through cameras detecting infrared radiation not normally visible to the human eye. Colors represent different temperatures and allow inferences where heat, and so energy, might be conserved in buildings. Unexpected areas of heat escaping from the building or cold air entering are made visible (Pearson, 2011; Fox et al., 2015). In sum, thermal imaging visualizations display information about energy use, which is normally invisible, in a colorful, vivid format.

The findings of four energy visualization studies provide insights into the role of thermal images in the field of domestic energy. The first small-scale study provided evidence that seeing thermal images increased energy efficiency actions. Householders were allocated to one of three conditions [thermal images of own home ($n = 17$), carbon footprint audit ($n = 17$), or control ($n = 9$)]. After one year, only the thermal image group reduced their carbon emissions from energy in the home, calculated from their household energy bills before and after the intervention. The behaviors they reported taking were directly related to the behaviors visible in the images (Goodhew et al., 2015a). In a second study, 87 householders received an energy audit. In addition, participants in the thermal image condition ($n = 54$) received thermal images of their own home but participants in the control condition ($n = 33$) did not receive any visualizations. Approximately 6 months later, householders who saw thermal images were almost five times more likely to report the installation of draught proofing measures compared to the control group (Goodhew et al., 2015a).

Having established evidence for a behavioral effect following exposure to thermal images, what do we know about the psychological process between energy visualizations and energy efficiency behavior? Householders see thermal images as highly desirable, and free voluntary thermal imaging offers trigger huge interest and immediate sign-ups (Goodhew et al., 2015b). An earlier exploratory qualitative study (Goodhew et al., 2009) examined the immediate reaction of ten householders at the moment they saw their tailored thermal images. Reactions were frequently (but not always) indicative of a fast attention capture. If householder attention was engaged successfully, this then led to an elaboration and reasoning process around homes, buildings, heat and energy, particularly in relation to householders' own behaviors. Participants' first response was often emotional and evaluative, e.g., "that looks dreadful!" This study provides first evidence that thermal images can attract attention to a complex set of issues that may be difficult to get across through alternative methods of communication (Sheppard, 2001, 2005; Midden et al., 2007). So, a key role of energy visualizations is in attracting attention, which is the first critical stage that can trigger an elaboration process taking the viewer from image to thoughts about energy and their own behavior (Goodhew et al., 2009).

In a fourth study, we investigated the importance of the tailoring element in the visualization. Householders ($N = 233$) were exposed either to thermal images of their own home ("tailored"), thermal images of other homes similar to theirs or a text only condition. Householders reported recalling thermal images more vividly than the text, irrespective of whether the images were of their own or another's home. However, own images were reported to be more intrusive: Householders said images of their own home "popped into their heads" more than images of others' homes. This suggests that thermal images led to more vivid mental images than text and that tailoring the presentation increased the intrusiveness of these mental images: they interfered with and interrupted normal thought processes. This is promising in terms of goal processes. If images are strong

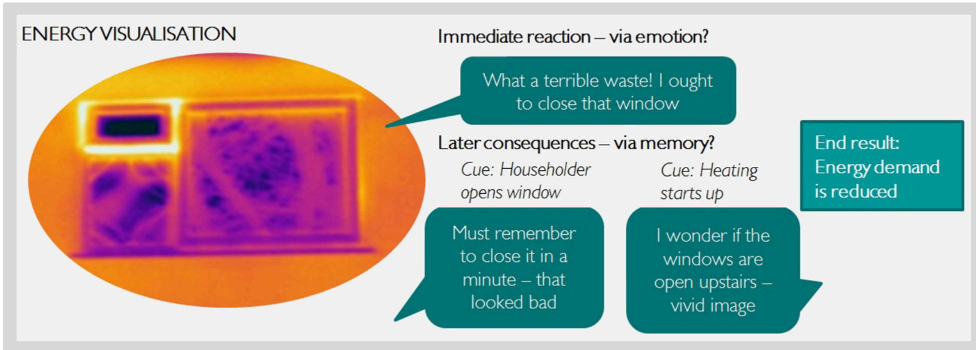

FIGURE 1 | Simplified illustration of suggested psychological processes around energy visualization using the example of a thermal image visualizing heat escaping through an open window in winter. Bright yellow color indicates higher temperatures.

enough to keep appearing in memory, this dynamic could explain increased motivation and action. Finally, those who received the tailored thermal images looked at their information more often and reported sharing that information with more people (Boomsma et al., accepted).

Beyond these cognitive processes, householders who saw tailored images were most likely to change their plans for their homes and reported stronger energy related intentions along with a stronger belief that they would benefit from draught proofing measures. In sum, the role of thermal image visualizations may be in communicating an energy efficiency message with increased vividness and "imageability" which more readily connects to the viewer's goals. This can be achieved partly by providing thermal images of typical homes but tailoring the images to people's own homes enhances the effect.

To summarize, our research on thermal images as a way of visualizing energy suggests that they can promote energy efficiency behaviors. They can attract attention, invoke emotion and trigger vivid images in memory later on. The images also communicate the problem of energy wastage in an intuitive and specific manner, aiding comprehension. Through these processes, they can enhance motivation, establish, and promote energy efficiency goals and trigger action.

LIMITATIONS AND FUTURE WORK

Much remains to be investigated in the field of energy visualization. While we have good evidence that one type of energy visualization (thermal images) can change householder decisions and behavior, we know very little about the effects of presenting different aspects of thermal images (e.g., inside vs. outside perspectives). Also, this example has only been applied to heat escaping from homes in cold winter climates, always using English homes. Other contexts and uses are conceivable that vary in terms of energy prices (after earlier pilot work, a larger trial is now planned in Vancouver, Canada, for example). Thermal imaging could also be used to visualize energy use associated with air conditioning in hot climates and we are currently exploring this new application. Moreover, work is needed to investigate other energy visualizations, for example to optimize the displays associated with the smart meter rollout, in order to maximize benefit from these vast nation-wide investment programs. Finally, visualization could be combined with interactive engagement, e.g., through virtual reality where users can explore energy issues for themselves (Stone et al., 2014).

CONCLUSIONS

Thermal images are one type of energy visualization that helps to engage householders in energy saving actions. We have summarized early evidence and psychological principles but further research is needed to test such integrative approaches that combine technical and social aspects intelligently. The area of energy visualization has huge potential that researchers are only beginning to exploit and can make an important contribution to the challenges surrounding climate change, energy security and fuel poverty.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct, and intellectual contribution to the work, and approved it for publication.

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The demand side in economic models of energy markets: the challenge of representing consumer behavior

Frank C. Krysiak and Hannes Weigt*

Department of Business and Economics, University of Basel, Basel, Switzerland

Energy models play an increasing role in the ongoing energy transition processes either as tools for forecasting potential developments or for assessments of policy and market design options. In recent years, these models have increased in scope and scale and provide a reasonable representation of the energy supply side, technological aspects and general macroeconomic interactions. However, the representation of the demand side and consumer behavior has remained rather simplistic. The objective of this paper is twofold. First, we review existing large-scale energy model approaches, namely bottom-up and top-down models, with respect to their demand-side representation. Second, we identify gaps in existing approaches and draft potential pathways to account for a more detailed demand-side and behavior representation in energy modeling.

Keywords: energy modeling, bottom-up, top-down, demand side, consumer behavior

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Edited by:
Tobias Brosch,
University of Geneva, Switzerland

Reviewed by:
Jay Zarnikau,
The University of Texas, USA
Sonia Yeh,
University of California Davis, USA

****Correspondence:***
Frank C. Krysiak,
Department of Business and Economics, University of Basel, Peter Merian-Weg 6, Basel CH-4002, Switzerland
frank.krysiak@unibas.ch

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Introduction

Reducing energy demand, or at least its growth, is one of the central objectives in the transition processes in many national and international energy markets. For example, the European vision of a low-carbon economy identifies energy efficiency as a key driver of the transition (European Commission, 2014), the Swiss Energy Strategy 2050 aims for a significant reduction of *per capita* energy consumption of 54% by 2050 (SFOE, 2012), and the IEA's World Energy Outlook considers a reduction in energy consumption as one of the main measures to achieve a significant reduction in CO2 emissions (IEA, 2014a).

Despite this importance of the energy demand side, there still exist significant knowledge gaps as to what factors determine energy demand and how it can be influenced. Besides descriptive statistics on specific energy consumption patterns and profiles and the technological linkage between service demand and energy needs (for example, different options to satisfy transport or heating demand), little is known about the underlying decision and behavioral processes. The fact that consumers seldom demand energy in itself but services and products which require energy for their provision links this challenge to a general understanding of consumption decision processes.

The energy demand aspects extend into the modeling dimension. In the last decades, energy system and market modeling has gained an increasingly important role within the policy process; i.e., forecasts based on models like the IEA World Energy Outlook using the World Energy Model (IEA, 2014b) or the Energy Trends of the European Commission based on the PRIMES model (European Commission, 2013) are important resources for economic and political decision makers. Model-based scenarios also form the basis of energy market processes like the network development planning in Germany and Switzerland (SFOE, 2013; NEP, 2014). Finally, models are used for *ex post* policy evaluation and are, apart from field experiments, the only way to gain knowledge about the necessary intensity of policy interventions. The existing energy system and market models were designed with a focus on the different technology options on the supply and transport side whereas demand was often assumed to be derived from external drivers like GDP or following classic price and substitution elasticities. Thus, they are limited in their capability to capture important psychological or social elements and aspects beyond the technology or price dimension.

The objective of this paper is to assess the role of the demand side and consumer behavior within economic energy market modeling, identify gaps in existing approaches, and design potential pathways to account for a more detailed demand side and behavior representation in energy modeling. In Section "Review on the Demand-Side Representation in Energy Market Models", we review existing model approaches for energy markets used for policy design and evaluation with special focus on their demand-side representation. Section "Energy Demand: Toward Richer Models" provides concepts to extend the existing models to facilitate a more detailed description of energy demand. In Section "Transferring New Approaches into Numerical Modeling", we discuss how these concepts can be used in numerical modeling and Section "Conclusion" concludes.

Review on the Demand-Side Representation in Energy Market Models

There exists a multitude of modeling approaches for energy-related questions. Within this section, we focus on large-scale models covering markets, sectors, or the whole energy system and economy.[1] Generally, those types of models can roughly be clustered in two streams: bottom-up (BU) and top-down (TD) models that are both able to address a specific range of relevant drivers (**Figure 1**). The former cover techno-economic models that provide a detailed representation of technical aspects of a market or energy sectors, like conversion or transport specifications, as well as microeconomic market representations that address the interaction of different market participants, like producers, traders, and consumers within wholesale markets. The latter cover macroeconomic models that are able to capture the interaction among several sectors and overall welfare effects. A related differentiation between the two clusters would be the terms "disaggregated" for BU models and "aggregated" for TD models (Böhringer and Rutherford, 2009).

Usually, the strengths of one model cluster are the weaknesses of the other. BU models allow a detailed representation of specific market characteristics, the impact of policies on a sector, and the costs and challenges of technological change. However, their focus on a single sector or a set of (energy) sectors limits the possibility to capture further cross-sectoral effects, the price driven influences are often limited to cost optimization, and they omit overall economy impacts like employment, trade, and income effects. Consequently for TD models the reverse is true (Herbst et al., 2012).

Following Hourcade et al. (2006) energy models can be structured along three dimensions: the technological, microeconomic, and macroeconomic detail. Generally, applied energy models are tailored to capture a specific dimension and have to omit other aspects. The first dimension represents the technological explicitness of a model including their ability to capture technological restrictions and how policies affect technological developments. The second refers to behavioral realism of the model including the representation of consumer choice and the impact of market structures on policy effectiveness. The third refers to macroeconomic feedbacks linking energy supply and demand to the general economic structure and development.

Bottom-up models typically rank high with respect to technological details and allow the modeling of different

[1]Small-scale analyses focusing on single processes or regional aspects, e.g., like micro-grids or single building optimizations, can address detailed demand aspects but naturally cannot capture general policy or market interactions.

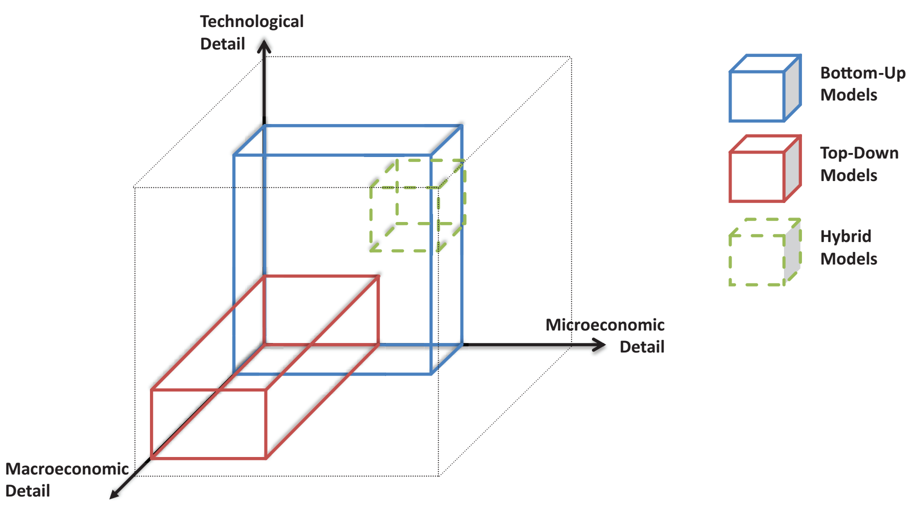

FIGURE 1 | Top-down and bottom-up model dimensions.

technology developments. Similarly, they allow the inclusion of microeconomic aspects like strategic company behavior or game theoretic approaches. However, typically BU model approaches that rank high on the microeconomic dimension need to rely on mixed complementarity formulations. This in turn limits the representation of technological details that require mixed-integer formulations like unit commitment of power plants. The opposite also holds. In contrast, TD models capture the macroeconomic interactions of economies and are based on the basic microeconomic rational of utility maximizing agents but lack technological detail and typically also fall short in addressing more detailed microeconomic behavior beyond perfect competitive market interaction.

Theoretically, a hybrid model capturing all three dimensions would provide the most structure for evaluating energy markets (Hourcade et al., 2006), but potentially at the expense of model focus and transparency of results. In recent years, research on models breaching the gaps between TD and BU has increased with several approaches of hybrid modeling emerging. In the following sections, we briefly present selected BU and TD models and methods as well as hybrid and other model approaches focusing on their representation of the energy demand side.

Bottom-Up Techno-Economic Models

Bottom-up models are characterized by their high degree of detail on the technology side and their representation of market structure and market architecture aspects. They are basically disaggregated representations of specific sectors or markets and therefore have to omit the more general economic interactions. They can be used both for short-term evaluations, like electricity market dispatch analysis, and long-term simulations, like investment scenarios. However, BU models rely on a set of externally defined parameters, which capture those economic aspects that are not covered by the model-like economic growth and demand or fuel prices of energy sectors. Defining these parameters is challenging, in particular for long-term evaluations, but BU models are one of the few options to simulate the impact of future conditions that deviate considerably from historic or current market conditions.

Bottom-up models are typically formulated as optimization problem or complementarity problem.[2] Especially techno-economic models that focus on supply and transport restrictions or operational details often rely on linear optimization techniques.

The large-scale energy system models are the IEA World Energy Model (IEA, 2014b), the PRIMES model (E3MLab/ICCS, 2014), the POLES model (Enerdata, 2014), and the MARKAL/TIMES family of models (ETSAP, 2014), which are covering several regions and sectors in a partial equilibrium setup. Typically, such large-scale energy system models consist of several modules or sub-models covering specific regions, sectors, or value-chain elements, which are linked via iterative simulations. Due to their long-term perspective, they capture investment decisions but neglect short-term dynamics. In recent years, those model families already started to breach the gaps between BU and TD modeling by integrating more macroeconomic aspects into their models.

Sectoral models focus on one specific fuel and the underlying markets. Consequently, there exist a large number of different models for the specific energy markets; for example, for electricity markets, the ELMOD model (Leuthold et al., 2012) or the DIMENSION model (Richter, 2011) for Europe and RFF's Haiku model for the US (Paul et al., 2009), the World Gas Model (Egging et al., 2010) or the COLUMBUS model (Hecking and Panke, 2012) for the global gas markets, the TREMOVE model for the transport sector (Capros and Siskos, 2012), or residential stock models for the building sector [see Kavgic et al. (2010) for a review], to name a few. The focus on a specific market or sector enables those models to capture much more details, such as network restrictions (e.g., pipeline or transmission line capacities), specific technology restrictions (e.g., power plant start-up times), and detailed regional and temporal resolutions (e.g., daily or seasonal demand patterns), than the large-scale energy system models mentioned above. Their specific model setup varies strongly and is often tailored to the specific research question at hand; that is, short-term technical questions, long-term investment aspects, or market design and strategic interaction, and consequently includes linear, non-linear, and equilibrium approaches.

In general, BU models are well suited to evaluate changes and impacts on the supply and transport side of energy markets. They can capture a wide range of different production restrictions and facilitate a corresponding detailed evaluation of policies. But their mathematical structure limits the representation of demand-side behavior. There are roughly speaking two main types of BU models with respect to price and demand-side representation, both being widely applied:

First, techno-economic BU models designed as *linear or linear mixed-integer optimization* problems. They are required to take the demand side as a fixed input and thus cannot capture price or budget feedbacks. Changes in the demand side can only be incorporated as shifts of the load level, for example, via a new hourly demand profile, due to demand-side management technologies; an increasing demand level, due to economic growth; or different demand scenarios based on energy efficiency assumptions. Furthermore, the linear structure leads to a classical cost optimal result that corresponds to a perfect competitive market framework, whereas imperfect competition cannot easily be captured within this model framework.

Second, BU models designed as *complementarity problems or non-linear optimization problems* incorporate demand-side functionalities, typically a relation between demand and price. Non-linear optimization problems can include welfare maximization instead of a pure cost minimization as the objective. This captures the price interaction but still keeps the models limited to perfect competitive benchmark outcomes. In addition, BU models using the equilibrium framework allow the representation of multiple agents with individual optimization rationales and thereby facilitate the simulation of strategic firm behavior, imperfect competition, or the impact of structural changes. Similar to the linear type BU models, the demand functionalities need to be

[2]Note that also TD models are formulated as complementarity problems. The differentiation between the BU and TD complementarity problems is in their coverage: while TD models are formulated as general equilibrium covering the whole economy with capital and labor effects, BU models only capture a subset of sectors or only a single sector and therefore are also termed partial equilibrium models.

externally defined, especially regarding the price elasticities. Consequently, general economic interrelations, such as budget effects or substitution-effects across markets, cannot be captured directly. However, the endogenous price formation makes it possible to cover direct price-quantity effects within the respective sector.

Top-Down CGE Models

Top-down models aim at representing the whole economy instead of only energy sectors and thereby capture the feedback effects across the economy. This modeling approach requires a high degree of aggregation and cannot represent the same technological detail as BU models. The most prominent macroeconomic model approach in energy economics are computable general equilibrium (CGE) models. Those models have a highly aggregated representation of the energy system and the other sectors of an economy. The equilibrium concept ensures that all modeled markets clear (supply equals demand on each market), given supply and demand characteristics. This equilibrium is obtained by endogenous price adjustments following the microeconomic rational of utility maximizing agents and profit maximizing firms. However, the agents in CGE models are highly aggregated; most often, a representative household is used. Due to their aggregation level and equilibrium concept, CGE models are well suited for long-term evaluations of changes in the policy or market frame and not for short-term operational simulations.

Due to the high abstraction level of CGE models, the production technology process is transferred into production functions with constant elasticities of substitution (ESUB). The different inputs and outputs are linked via nesting structures; that is, the energy input into a production function is itself an aggregate of different energy types, like electricity and fossil fuels that can be substituted for each other. As these elasticities determine the degree of substitution between inputs, they are thereby an important driver of the effects of policy changes. To capture the effect of technological change in the energy sector – basically a shift of the production functions – exogenous shift parameters are often used, like the autonomous energy efficiency index (AEEI). The AEEI represents a price-independent energy efficiency increase, which is sometimes used to carry out sensitivity analyses.

The same logic is applied to the demand side of CGE models. **Figure 2** shows an exemplary demand-side structure for a CGE model with detailed energy specifications. Demand is derived from maximizing the utility function of a representative household, given a budget restriction. Consumption and other "goods," such as leisure time, form the aggregated utility good. Consumption itself is split into direct energy use and consumption of other goods. The energy use in turn can be satisfied by different fuels which can be substituted for each other given the elasticity σ^E; that is, switching from oil to electricity for heating. The energy needed for the other goods, the embedded energy, is obtained by a similar structure on the production side. This allows CGE models to capture indirect energy effects due to changes in consumption.

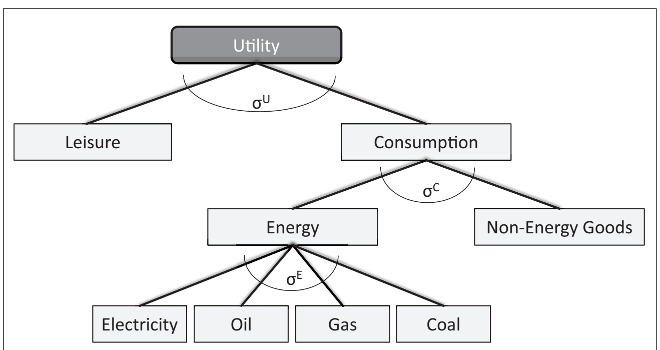

FIGURE 2 | Exemplary nesting structure of energy specific demand side.

There exist a large number of CGE models that address different economic aspects. Bergman (2005) provides a general introduction to CGE models and a review on different environmental- and resource-related CGE models. Those models can be (broadly) clustered into global, multi-regional, and single-country CGEs. Within the first group, examples are given by the MIT-EPPA model (Paltsev et al., 2005) and the DICE and RICE model family (Nordhaus, 2012). The GEM-E3 model of the European Commission (Capros et al., 2013), the related GEMINI-E3 model (Bernard and Vielle, 2008), and the PACE modeling framework (Böhringer et al., 2009) are examples for energy-related multi-regional models. Finally, the GENESwIS for Switzerland (Vöhringer, 2012) and the MIT U.S. Regional Energy Policy Model (Lanz and Rausch, 2011) are examples for single-country CGEs.

Top-down computable general equilibrium models are well suited to capture price-based demand side effects across different sectors via budget effects. This is particularly important for the estimation of rebound effects that result from such indirect effects. They also are well suited for public finance evaluations of taxes and other instruments. However, the underlying parameters for the different ESUBs and the AEEI are typically based on estimates and expert judgments (Bataille et al., 2006). This poses two challenges: first, data and estimations on both ESUBs, and particular AEEI, are incomplete, and second, estimates based on past and present data do not necessarily have to be an accurate description of future behavior making TD models less suited for the analysis of extensive system shifts in comparison to BU models.

Hybrid Models and Other Model Approaches

Due to the limitations of both BU and TD approaches, researchers are developing methods to merge both lines of models for policy analyses. The resulting hybrid models can be clustered into three categories (Böhringer and Rutherford, 2008): First, soft-linked models, in which independent BU and TD models are linked by passing data between the models or via direct convergence mechanisms, as, for example, in Schäefer and Jacoby (2006), who link the MIT-EPPA CGE model with the MARKAL model. This approach faces the challenge of consistency of the disaggregated and aggregated results; that is, the electricity generation of different power plant types of a BU electricity model run need to match the aggregated fuel consumption of the electricity sector in the TD model. Second, a reduced form version of one model is incorporated into another model, as, for example, in Bosetti et al. (2006) or Leimbach et al. (2009). Third, integrating technological details directly via the mixed complementarity problem formulation of a CGE model, see, for example, Böhringer and Rutherford (2008, 2009).

From a demand perspective, hybrid approaches facilitate the combination of detailed sectoral effects, like shifts in demand profiles, with general macroeconomic feedbacks, such as indirect rebound effects. This is of particular relevance for energy efficiency evaluations. Furthermore, the potential to model higher temporal resolutions in BU approaches makes it possible to combine short- and long-term economic feedbacks. Nevertheless, the demand representation is still limited to the above presented characteristics and focused on quantity-price relations and/or externally defined levels and trends.

In addition to CGE models and optimization and partial equilibrium BU models, there are a number of additional model approaches in energy economics [see Catenazzi (2009) and Herbst et al. (2012)]. These include input–output models, system dynamics approaches, and econometric models. The latter often include multiple consumer groups [i.e., the E3ME model has 13 types of household, Camecon (2014)]. But due to their reliance on historic data, they are not well suited to analyze significant system shifts. On the BU side, there are furthermore simulation models and agent-based models. The former are often more technology driven and can represent whole energy systems with great detail; see, for example, the LEAP model (Heaps, 2012). The latter results from a relatively new model approach in energy economics [e.g., see Weidlich and Veit (2008) for a review of electricity market related agent-based models]. Instead of a closed mathematical market formulation, individual market participants are modeled as agents with autonomous behavior that interact with each other. This makes it possible to model different behavior of the market participants and thereby capture choice related aspects.

Summarizing the different existing energy model approaches, we see that they are typically designed to capture supply side related market aspects while demand-side aspects are much less detailed. This is partly a result of the underlying computational structure but also a result of the historic market development; for a long time, electricity and natural gas systems were regulated markets in which cost optimal energy supply was the main focus. Furthermore, most of the recent energy-related developments took place on the supply side, such as, the emergence of renewable energy technologies.

It is thus not surprising that existing models typically lack endogenous demand-side influences beside price-quantity relations. Furthermore, most models treat the demand side as an aggregate with little detail on specific consumer aspects and differentiated consumers.[3]

Despite these problems, existing models are well suited to analyze small, price-induced changes on the demand side as well as the effects of pre-defined (scenario-based) changes to energy consumption on markets and energy supply. However, with an increasing focus on energy efficiency and the liberalization of former monopolistic markets, the demand side will become increasingly important: policies directly aimed at end users will increase, companies will need to compete for consumers with better products or services, and finally consumer will also become active market participants providing their own energy supply and storage potential as 'prosumers'. In particular, it will be necessary to develop models that capture consumer choices with respect to energy provision and that can describe the relation between changes in individual behavior and demand-side policies.

[3]Note that especially energy system models often rely on different demand modules (e.g., one for transport demand, one for heating demand etc.) and combine/aggregate detailed consumer information to derive those modules. Many demand aspects are therefore part of the parameterization and not endogenous model aspects.

Energy Demand: Toward Richer Models

As discussed above, most applied economic models describe energy demand as being a function of prices and income only. From a theoretical perspective, this is warranted by the basic microeconomic model of consumer choice, where an individual maximizes her utility $U(e, x)$ over a bundle of energy goods e and other goods x subject to the condition that total expenditure does not exceed income y for a given vector of energy prices z and other prices p:

$$\max_{e,x\geq 0} U(e,x),$$
$$s.t.\ z\,e\ +\ p\,x\ \leq y.$$

This results in a demand function for energy $e = f(z, p, y)$. Under conventional assumptions, demand for each energy good is a decreasing function of this good's price and an increasing or a decreasing function of the prices of other goods, depending on substitution possibilities. Typically, the above consumer is used in the sense of a (descriptive) representative consumer, that is, the consumer is used as an "average" of all consumers, so that the characteristics of aggregate demand (over all consumers) are identical to the characteristics of this consumer's energy demand. This approach forms the basis of most CGE models, whereas BU models rely on further simplifications.

The above basic setup is useful to describe the response of energy demand to price changes, in particular, the effects of changes in energy markets or of some policy instruments, such as energy taxation. In fact, numerous studies have assessed the price responsiveness of demand for different energy goods, see, for example, Filippini (2011) or Krishnamurthy and Kriström (2015). Furthermore, it can be used to examine simple indirect phenomena, like the above discussed rebound effects.

However, to assess other types of demand-side policies or more general effects, the model lacks structure. A simple but powerful extension is to consider heterogeneous consumers, for example, groups of consumers that differ regarding their income or preferences. Such an extension makes it possible to assess the distributive impacts of energy policies. Furthermore, such a model can be used to assess potential benefits of group-specific interventions.

But even with this extension, the model does not capture many effects that have been found to be relevant in field studies.[4]

[4]For a review of energy-related intervention studies, see, e.g., Abrahamse et al. (2005).

Most importantly, the above model assumes that consumers are perfectly aware of all actions to reduce their energy consumption, so that information-based policies are ineffective by definition, and that there are no interactions among consumers, apart from market interactions. Furthermore, preferences are considered as being given and constant, so that there is no leeway for changes to individual lifestyles that are not "forced" by changing conditions (such as, prices or income).

In the next subsections, we will discuss how the above model can be adjusted in simple ways to capture the potential relevance of information, social interactions, and changing preferences.

Modeling the Influence of Information on Energy Demand

To make room for potential effects of information-based approaches to steer energy demand, a necessary assumption is that consumers are not perfectly aware of all options for changing their energy demand. For example, they might not know which energy-efficient appliances exist, what quality and prices they have, and where they can be bought. Thus, if they want to change their behavior, they need to *search* for new solutions. There is a long tradition of search models in economics, with applications mostly to labor markets, explaining price dispersion, and innovation. Chandra and Tappata (2011) use such a model to explain differences in gasoline prices among stations; Kortum (1997) as well as Makri and Lane (2007) use a search model to explain how firms find new technological solutions.

To transfer the main insights of these models to individual energy demand, it is useful to assume that consumers need to invest in appliances (some goods x, in our above notation) to alter their ability of adjusting energy use e. However, they are not aware of the properties of the relevant goods x and thus need to spent time or money searching for an appliance that meets their requirements. From a modeling perspective, we could assume that consumers know a distribution of possible characteristics of appliances, that is, they know which qualities, costs, usage characteristics, and energy reductions are technically feasible. However, without gathering information, they do not know which appliance has which properties.

Thus consumers can either buy an appliance without this information or invest time (modeled via fixed opportunity costs S) to ascertain the characteristics of one appliance (they randomly draw an appliance from the overall distribution and learn its properties). If they invest in this search, they can afterward decide to buy this good or to research another one. This decision will be made based on the overall distribution of possible characteristics, that is, on their knowledge what is feasible; whenever the good comes sufficiently close to having the preferred characteristics among all feasible goods, a consumer will not invest in a new search (the probability of finding a better solution is too small) and rather buy this good.

Such a model is able to describe some interesting effects. First, changing energy consumption induces one-time costs (search costs). Thus potential gains in energy efficiency will only be reaped, if these gains compensate for the search costs, in other words, small changes to energy prices will have little, but somewhat larger changes might have substantial effects. Furthermore, the model explains why different consumers will resort to different solutions in the short run (and thus explain technological variety, e.g., different alternatives to conventional light bulbs) but might converge to similar solutions later on, when they observe the choices of others. Finally, and most importantly, the model can describe an impact of information-based policies. Such policies would lead to a reduction of search costs, implying an earlier start of the search process and thus making it easier to reap small gains in energy efficiency.

However, as preferences remain unchanged, the model also highlights an important constraint of information-based policies: Such policies only reduce frictions, and they do not alter a consumer's overall assessment of whether it is beneficial to reduce his energy consumption. Thus in the context of this framework, information-based policies will be ineffective; if consumers do not reduce their energy consumption, because the individual gains (savings from using less energy) do not cover the individual costs (in terms of expenses or reduced quality of life).

Social Interactions and Social Norms

A different way of influencing individual behavior is to provide information about the behavior of others or (implicit) information about social norms regarding energy consumption. This approach has been found to be effective in a number of studies. For example, Allcott (2011) shows in a large-scale field study with 600,000 households that using such non-price instruments can have similar short-run effects on total energy consumption as an 11–20% increase in energy prices.

Again, there is some tradition in other fields of economics of modeling social norms. A convenient approach is to include a "disutility" of not meeting a social norm in the description of individual behavior, see, for example, Lindbeck et al. (1999), where such an approach is used in the context of social security. Other contexts where this modeling approach is used are the explanation of tipping behavior, see, for example, Azar (2004), and green consumption, as in Nyborg et al. (2006).

In a general framework, this can be modeled by a slight extension of the above basic model. To this end, assume that the utility of individual i (out of n individuals) depends not only on her consumption (e_i, x_i) but also on a social norm N:

$$\max_{e,x\geq 0} U_i(e_i, x_i, N),$$
$$s.t.\ z\, e_i + p\, x_i \leq y_i.$$

The social norm is in turn a result of the behavior of all individuals in the society (which might, however, have different influence on norm formation):

$$N = g\left(e_1, x_1, e_2, x_2, \ldots, e_n, x_n\right).$$

In such a model, changes in individual behavior can result in adjustments of social norms, which in turn will lead to further changes in individual behavior.[5] This approach thus introduces

[5]To ensure that this process converges, it can be useful to assume that the second (norm-induced) effect on individual behavior is always smaller than the original change in behavior.

a feedback effect in the basic model. Furthermore, it is possible that there are several equilibria, for example, an equilibrium with low and one with high energy consumption, which are each stabilized via the endogenously formed social norm (Lindbeck et al., 1999).

An information-based policy could be described either as manipulating the social norm or as making people more aware of an existing norm. In the first case, it might be possible to suggest that the norm is low energy consumption, which could move the system to an equilibrium with lower energy consumption (if multiple equilibria exist). In the second case, the policy could increase the disutility from not being close to the norm, which would induce both a direct change in behavior and an according adjustment of the norm. Such increases in disutility could be achieved by providing information about the behavior of other consumers. An example is given in Traxler (2010), who shows how changing the beliefs of tax payers regarding the incidence of tax evasion (and thus their disutility from not meeting a social norm) can change overall outcomes rather drastically.

A slightly more elaborate version of the above model would not use a single social norm but rather a set of group-specific norms, whose formation may be interrelated. This would facilitate the modeling of social interactions or peer pressure within groups.

However, a major problem is the quantification of the effects that social norms have on individual decisions. Some authors argue [see, e.g., Camerer and Fehr (2004) or Krupka and Weber (2013)] that laboratory experiments can be used to gain at least an approximate quantification. Others, such as Levitt and List (2007), are more critical and point out that questions regarding a limited transferability of experimental situations to every-day-behavior have particular relevance for the case of adherence to social norms. Field experiments provide another option, see, for example, Shang and Croson (2009), who study the influence of social information on public good provision. However, as field experiments are rather costly, this option usually implies a transfer across contexts and countries, as it is not possible to implement a field experiment in every situation where the influence of social norms on energy use needs to be assessed.

Modeling Changing Preferences and Sufficiency

Another, much discussed, approach toward reducing energy consumption is *sufficiency*. This term is used in the literature in different ways [see, Oikonomou et al. (2009) or Alcott (2008) for an overview]. Most importantly, sufficiency needs to be disentangled from efficiency, which is not trivial, as the economic concept of efficiency covers both changes in technology and changes in behavior.

Often, sufficiency is considered to be an enforced or voluntary frugal way of living (Oikonomou et al., 2009). In case of enforced frugality, this might imply reduced individual well-being. In contrast, if sufficiency is to be chosen voluntarily, an individual has to get a sufficient recompense for the reduced consumption, which might take the form of an increased self-esteem, utility from contributing to a socially desirable outcome, or an increase in leisure time (due to be able to cope with less income).

However, a salient question is if sufficiency gains exist, why have they not yet been fully reaped? Building on the concept of social norms discussed in the preceding subsection, one argument might be that different societal equilibria exist and individuals are "trapped" in a situation where the benefits of sufficiency cannot be reaped, because they depend on similar behavior by others. This would reduce the problem of modeling sufficiency to the cases discussed in the preceding subsection and interventions toward sufficiency would need to address social norms.

A different approach to sufficiency would be to remain on the individual level and to assume that individuals can only assess the quality of life in situations that they have already experienced. Thus they know how to live in the way they are currently living and how to react to small shocks. However, there might be different ways of living that reduce energy consumption without sacrificing well-being that the individual has not yet experienced and thus does not know.

In terms of modeling, we could assume that preferences consist of a set of local preferences (each defined in a neighborhood of a given consumption bundle) out of which an individual knows only one (her current) local preferences. The other preferences (i.e., ways of living) are not known to exist but their properties (how much utility can be gained, how goods can be substituted) are uncertain until this way of living has been tried. In such a setting, a risk-averse consumer would not alter his way of living until "forced" to do so (either by changing energy prices or by other interventions). Once a new way of living has been tried, the respective local preferences become known. If the driving force of the change vanishes (energy prices come down again), the consumer might either maintain this way of living or switch back to her original consumption pattern.

The benefit of this approach is that it captures much of the essence of the sufficiency concept and introduces an effect into the energy economic modeling that is not present so far: a one-time intervention can have lasting effects for some but not all parts of the population. For example, an oil price shock might initially increase the number of people not using cars. However, once oil price go down again, some consumers might switch back to their original way of living, whereas others have experienced a new and preferred lifestyle, which they voluntarily maintain.

However, it should be noted that if sufficiency gains are to be depicted in a model, this model cannot use *per capita* consumption, GDP, or total costs to assess demand-side policies. Rather, a measure of welfare has to be used that is based on individual utility and that captures either utility derived from adhering to social norms or the above mentioned uncertainty. Whereas this is common in theory, it is hard to implement in numerical models, as the necessary data is lacking.

Transferring New Approaches into Numerical Modeling

Obviously, existing numerical energy models will need adjustments and extensions to address the challenges in relation to increased energy efficiency and demand-side policies. For all changes, a necessary first step is the inclusion of heterogeneous consumers into the existing model structures. For CGE models, this basically refers to a more disaggregated structure on the demand side of the market transferring the oftentimes single representative household into several household types; for example, households representing different income classes that differ in their demand elasticities for specific goods.[6] This is less a modeling challenge, as the basic computational model structure remains unaltered, but more a question of data availability. Detailed data on different household types, their income, the split of income across sources, and consumption choices would be needed. For BU models, such a disaggregation is possible but will only result in a differently shaped aggregate demand function without much impact on overall computational model structure. Again, the main bottleneck for such a development is data availability like sufficient spatial or temporal resolution.

Building on this, it might be feasible to include richer models, such as those presented in Sections "Modeling the Influence of Information on Energy Demand," "Social Interactions and Social Norms," and "Modeling Changing Preferences and Sufficiency." Some extensions might be fairly easy to achieve, for example, the basic structure of norm-based interactions does not differ much conceptually from the inclusion of public knowledge on the production side in endogenous growth [see, for example, Bretschger and Suphaphiphat (2014)] and should thus be transferable to numerical CGE modeling. Including sufficiency or search processes would be much more difficult, as this requires the inclusion of uncertainty, which is hard to achieve in large-scale numerical models.

For BU models, a stepwise or time-dependent model structure as used in dynamic investment models, unit commitment models, or rolling planning models can be used as starting point. Within a period t the consumption decision is derived from externally defined parameters including, for example, norm driven aspects. The resulting consumption will then have an influence on the impact of norms in the following period $t+1$. Whether this influence is handled outside the model, that is, by adjusting the demand function accordingly, or within the model depends on the scope and structure of the model. The former should easily be accommodated by most BU model approaches, including linear optimization problem following a myopic logic. The latter introduces dynamic elements similar to path dependent investment aspects which increases the model complexity.

However, the proposed concepts require a quantification of their effects before they can be included into numerical models. Given our current knowledge on energy demand and particular on non-price driven influences this represents a significant non-modeling challenge. Consequently, to properly address those aspects in economic models we will first need a better understanding of the fundamental drivers of consumers energy demand.

Conclusion

Overall, this paper has two main messages. First, most of the currently available applied energy models do not use sophisticated approaches to describe the demand side. In fact, most models cannot describe or assess demand-side interventions apart from price changes. However, the second part shows that this is not a restriction imposed by the general economic approach to modeling consumer behavior. Much richer models are feasible and are used in other fields of economics. In particular, it is feasible to model many effects, such as social norm or social interactions that have been found to be relevant in field studies.

In our view, there are two reasons why these approaches are currently not used in energy modeling. First, there is a lack of demand. For decades, energy policy has focused on the supply side; whereas billions have been spent to enact changes in energy supply, demand-side policies have typically a small budget.[7] Accordingly, demand for policy assessments is biased toward supply side policies and thus most applied energy models have a highly detailed supply and a fairly simple demand structure.

Second, applied modeling requires not only concepts but also data. Whereas data on energy supply is abundant, there is a lack of data regarding the structure of energy consumption and its main determinants apart from prices and technologies. Few countries have a micro census that includes more than some elementary energy-related items, so that projects aiming for a better description of the demand side have to collect their own data. Given the different foci of such projects, there is little chance of combining their data to a sufficiently broad database.

As energy strategies in many countries are based on a strong reduction in *per capita* energy consumption, the first reason will vanish rather rapidly; the need for more qualified assessments of demand-side policies will strongly increase within the next years. However, the second bottleneck (missing data) will not dissolve in a likewise manner. Thus if better models of energy consumption are desirable, generating the necessary data should be the main priority.

The need for detailed data also extends to a more general lack of understanding the fundamental drivers and mechanisms of energy demand beyond the technological layer. Overcoming this knowledge gap will require fundamental research in social and political science as well as psychological and consumer behavior research and the transfer of those insights into the economic model community. How such an integrated interdisciplinary framework could be achieved is addressed in Burger et al. (2015) in the same issue of Frontiers in Energy Research.

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[6]There are numerous examples of this approach in the context of social security evaluation and climate policy. For example, Nijkamp et al. (2005) use this approach to study inequality across countries under different international climate policy regimes and Yang (2010) uses different local households in a CGE model.
[7]A notable exception is policies targeting energy efficiency in residential buildings.

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Advances in understanding energy consumption behavior and the governance of its change – outline of an integrated framework

Paul Burger[1]*, Valéry Bezençon[2], Basil Bornemann[1], Tobias Brosch[3], Vicente Carabias-Hütter[4], Mehdi Farsi[5], Stefanie Lena Hille[6], Corinne Moser[4], Céline Ramseier[7], Robin Samuel[8,9], David Sander[3], Stephan Schmidt[1], Annika Sohre[1] and Benjamin Volland[5]

[1] Sustainability Research Group, University of Basel, Basel, Switzerland, [2] Enterprise Institute, University of Neuchâtel, Neuchâtel, Switzerland, [3] Department of Psychology, Swiss Center for Affective Sciences, University of Geneva, Geneva, Switzerland, [4] Institute of Sustainable Development, Zurich University of Applied Sciences, Winterthur, Switzerland, [5] Institute of Economic Research, University of Neuchâtel, Neuchâtel, Switzerland, [6] Institute for Economy and the Environment, University of St. Gallen, St. Gallen, Switzerland, [7] Center for Energy Policy and Economics, ETH Zurich, Zurich, Switzerland, [8] Institute of Sociology, University of Bern, Bern, Switzerland, [9] Social Research and Methodology Group, University of Basel, Basel, Switzerland

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Joni Jupesta,
United Nations University, Japan

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Jay Zarnikau,
The University of Texas at Austin, USA
Payman Dehghanian,
Texas A&M University, USA

***Correspondence:**
Paul Burger,
Sustainability Research Group,
Department of Social Sciences,
University of Basel,
Klingelbergstrasse 50,
Basel 4056, Switzerland
paul.burger@unibas.ch

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Transforming today's energy systems in industrialized countries requires a substantial reduction of the total energy consumption at the individual level. Selected instruments have been found to be effective in changing people's behavior in single domains. However, the so far weak success story on reducing overall energy consumption indicates that our understanding of the determining factors of individual energy consumption as well as of its change is far from being conclusive. Among others, the scientific state of the art is dominated by analyzing single domains of consumption and by neglecting embodied energy. It also displays strong disciplinary splits and the literature often fails to distinguish between explaining behavior and explaining change of behavior. Moreover, there are knowledge gaps regarding the legitimacy and effectiveness of the governance of individual consumption behavior and its change. Against this backdrop, the aim of this paper is to establish an integrated interdisciplinary framework that offers a systematic basis for linking the different aspects in research on energy related consumption behavior, thus paving the way for establishing a better evidence base to inform societal actions. The framework connects the three relevant analytical aspects of the topic in question: (1) it systematically and conceptually frames the objects, i.e., the energy consumption behavior and its change (explananda); (2) it structures the factors that potentially explain the energy consumption behavior and its change (explanantia); (3) it provides a differentiated understanding of change inducing interventions in terms of governance. Based on the existing states of the art approaches from different disciplines within the social sciences, the proposed framework is supposed to guide interdisciplinary empirical research.

Keywords: energy-related consumption patterns, behavior change, interdisciplinary framework, governance of individual behavior

Problem Statement

It is commonly agreed upon that the transition of the currently existing energy system will require not only technological innovations and substitution of fossil fuels on the supply side but also behavioral changes regarding the individual energy consumption on the demand side. Households, i.e., by definition one or more individuals sharing a living space, consume approximately one-third of the direct energy in Switzerland, mobility not included (BFE, 2014). As individuals are responsible for a substantial share of the total energy consumption, achieving the societal goals of the energy transition also requires reduction of individual energy consumption. Related goals are included in many of the countries' energy strategies (e.g., DECC, 2012), and one of the scientific tasks in the field of energy research is to provide evidence bases on how to achieve the goals of substantially reducing individual energy consumption.

Regarding the latter, there are two main strategies: improving energy efficiency and enhancing sufficiency. So far, however, there is no great success story to be told regarding the aspired reduction. Despite many efforts, there is no clear evidence that the total energy consumption of individuals has been reduced substantially during the last decade. In Switzerland – comparable to other industrialized countries – the total final energy consumption of private households in 2012 exceeded the consumption in 2000 by 4.5%, instead of the intended decrease (BFE, 2013: 5). A number of related barriers have been identified in numerous scientific studies and they include a lack of information and motivation to reduce energy consumption, energy as a quasi invisible factor, relatively small financial incentives for energy saving compared with firm daily routines, symbolically loaded activities, or specific decision heuristics etc. (Reddy, 1991; Shove, 1997; Lorenzoni et al., 2007; Steg, 2008). Additionally, rebound effects have counteracted realized efficiency gains (cf. Greening et al., 2000; Darby, 2007; Herring and Roy, 2007; Sorrell et al., 2009; Van den Bergh, 2011). Economists tend to refer to the "energy efficiency gap" to explain the meager success (Jaffe and Stavins, 1994; Gillingham and Palmer, 2014). Advocates of sufficiency strategies complain about the one-sidedness of efficiency and argue that only combined strategies will lead to the intended reduction goals (Sachs, 1993; Darby, 2007; Notter et al., 2013). In addition to individual barriers, there are also frame conditions that strongly influence behavior patterns but over which individuals have little influence (Scheuthle et al., 2005). These conditions include among others the persistent effects of existing appliances, the landlord/tenant dilemma, availability of facilities, market, and policy failures, as well as social norms and conventions. To some extent, there is certain progress in changing behavior and research has shown that with adequate measures (e.g., individual consulting, commitment strategies, campaigns making use of social norms etc.) applied at the right time (e.g., windows of opportunity where habits can be broken), behavior can actually be changed (Nolan et al., 2008; Schäfer et al., 2012; Baca-Motes et al., 2013). However, societies are not yet really on track with the ambitious goals they aspire to. It seems that both our understanding of the determining factors of energy-related consumption and our understanding of the drivers and barriers of change need to be improved for making progress toward reduced energy consumption in households.

The distinction between understanding behavior and understanding change of behavior has been introduced on purpose. Unfortunately, these two explanatory goals are not always kept separate in the literature. The first explains energy consumption behavior (ECB) as it is today, and the second explains its change. As this distinction is decisive and allows us to unfold the different scientific tasks, we start with looking at it more closely.

Because any explanation is composed of two elements, namely of what has to be explained (the explanandum) and what it is explained with (the explanantia), the first goal of "explaining ECB" implies answering the following two questions:

(1) What is ECB?
(2) Which factors determine ECB?

Question (1) is by no means trivial. An economist for example could easily say that it is a demand function we are looking for. But does this denote demand for energy or demand for energy services (as we will argue for)? And does "demand" capture e.g., the daily routines in consuming embodied energy? An explanation is basically dependent upon what is to be explained. As a description of the components of ECB is far from being evident, answering question (1) is a first indispensable step toward clarifying the research object (explanandum). Question (2) then addresses the explaining factors of the behavior in question (explanantia).

However, explaining "ECB" includes neither the temporal dimension of change nor the reduction goals. Hence, there is a second explanatory goal, namely explaining "change of energy consumption behavior toward reduction" (cf. also Darnton, 2008 for distinguishing two explanatory endeavors). Accordingly and following the above made distinction between explanandum and explanantia, two further questions can be formulated:

(3) What is "change of ECB?"
(4) Which factors explain changes of ECB?

As with question (1), answers to question (3) are not as straightforward as it first may seem. First, answers are dependent on the approach chosen for question (1). For example, it makes a huge difference whether embodied energy is included or not. Second, a clear definition of the scope of "change" is mandatory. Are we simply talking in terms of reduced kJ on the individual level or do we broaden "change" to capture a changed perception of what makes up quality of life (cf. Mourik and Rotmann, 2013)? Hence, analyzing behavior and analyzing its change force us to first clarify the object of interest (explanandum).

Question (4) also asks for clarification, as the term "factors explaining changes" (explanantia) could be interpreted in two ways. First, it can refer to those factors that explain behavior according to question (2). We will argue below that the types of factors are the same as in question (2), e.g., including milieu related aspects, decision heuristics, spontaneous developments, norms etc. As different behaviors ask for different determinants, we need to identify the variation of the factors within the types. Second, "factors" can also refer to interventions, political instruments etc., i.e., to elements directed to steer behavior toward a change. However, we do not use the term "factor" in that second sense. Instead, we propose to add a fifth question:

(5) What are the constituents to be taken into account to successfully govern change of energy-related consumption behavior?

Question 5 deals with the realm of governance. And again, answers are not as straightforward as it seems. Given the complex scientific debate on "governance of societal change," it is worth considering this topic and refraining from an exclusive focus on political instruments.

An abundance of literature already contributes to many aspects within the sketched explanatory fields. Whether the current state of the art, however, copes with the indicated distinctions and their inherent complexity is at least doubtful. Despite the large number of scientific studies, science still struggles with understanding ECB and the triggers for changing it. Existing scholarship has for example so far been largely dominated by studies on price sensitivity, "rational actor"-models, drivers and barriers for accepting new technologies, and rebound effects. Studies on socio-cultural aspects (e.g., milieu, lifestyles) or on routines can be found only to a much lesser extent. Moreover, recent psychological and consumer behavior research has pointed to other factors such as cognitive heuristics, emotions, moral and social norms, and personal core values (Kahneman, 2003; Brosch and Sander, 2013). In addition and most importantly, the scientific state of the art displays strong disciplinary splits (Keirstead, 2006) to the effect that there is only little understanding of the interrelations among different aspects of ECB across the different fields such as psychology, economics, and the social sciences. Against the backdrop of the existing difficulties for answering questions (1)–(5) and the dominant disciplinary splits, we see at least six expectations motivating this paper's undertaking to establish an integrated framework for analyzing ECB and its change:

(1) Facing the complexity and the patchwork-character of consumption and related explanations, capturing the interplay between different domains, e.g., social segmentation and decision heuristics or governance and emotional factors, becomes an important task. Stern (2014) (p. 44) puts the point nicely: "Researchers adhering to a disciplinary approach often fail to examine the possibility that these variables may matter more for some choices than others, that they interact with other factors […], and particularly that they may not matter much for the household choices that have the greatest implications for overall energy use." Only by bringing together the manifold factors will we be able to provide well-founded evidence for societal decision-making. (2) Given the aggregated reduction goal, comparisons between as well as aggregation over the different subsectors of consumption with their different explanations and different settings for behavioral changes are needed – presupposing a common basis. (3) Additionally, the variations in ECB direct us toward taking a closer look at the demand side and disentangling the very broad notion of "demand," among others in looking at well-being aspects linked to demand. (4) The two explanatory tasks – explaining ECB and explaining its change – are often confounded within the literature. An interdisciplinary framework could help clarify the different tasks by not only cutting clean but also by integrating these two explanatory perspectives; bringing different disciplinary competences together. (5) The potential of governance to steer ECB remains unclear. As modern energy consumption patterns are diverse, certain governance means could have different impacts on different consumption sectors for different individuals (Owens and Driffill, 2008). Moreover, individuals are normally addressed by complex sets of steering measures. How these different policies interplay with each other is hardly understood so far (Oikonomou and Jepma, 2008). (6) There are strong variations across disciplines in terms of theories and methods. Different theories and different methods capture different aspects of a field and hence, can be brought together, e.g., for triangulation or complementary insights.

We expect an interdisciplinary framework to offer a systematic basis for linking the different aspects and supporting the different disciplines to learn from the strengths of the others to provide more integrated results. It could support paving the way to address the intersections between different factors, providing a basis for comparisons and aggregation and for disentangling the demand side, distinguishing between different explanatory tasks, having all available scientific competences regarding the different explanatory facets, and collecting disciplinary competences for triangulations and the like. Some integrated models have already been set up in (more or less) interdisciplinary approaches [cf. Section "Paving the Way Towards an Integrated Framework (Relevance and Gaps)"]. While recognizing the instruction value of these models, we nevertheless follow Wilson and Dowlatabadi's (2007) statement that there is still an academic gap regarding integrated, interdisciplinary models or frameworks that systematically capture the different explanatory tasks regarding ECB and its (governed) change. Our paper contributes to closing this gap.

Last but not least, there is a practical add-on. The authors are all members of the work package on change of behavior within the newly founded Swiss Competence Center for Research in Energy, Society, and Transition (SCCER-CREST)[1]. We expect the proposed framework in this paper to not only guide our particular research toward the commonly defined goals, namely, providing empirical evidence for business, political, and civil society actors on the change of ECB, but also to provide a general guidance for the research undertaken in SCCER-CREST (Krysiak and Weigt, 2015).

Paving the Way Toward an Integrated Framework (Relevance and Gaps)

Most of the already suggested integrated frameworks try bringing together insights from different disciplines to understand ECB. There are at least three different types of such frameworks. The first tries to capture the field as a socio-technical system, bringing in social and engineering sciences. Hitchcock (1993) for example, distinguishes between the physical and the human subsystem each containing trigger points for either technical or social change. The second is mainly oriented toward economic modeling that pays attention to interaction between macro and micro factors.

[1] http://www.sccer-crest.ch

Dholakia et al. (1983) e.g., argued that micro choices of the individuals (social, psychological factors) are delimited and defined by macro choices (political, economic factors); the latter (e.g., settlement structures) being often more relevant than the former. A third type tries to represent the different factors by basically relying on some specific theory from sociology. Wilk (2002) and Keirstead (2006) suggested interdisciplinary frameworks based on sociological approaches from Bourdieu, or Actor Network Theory (ANT) linked with Agent Based Modeling. There are also blends such as Stephenson et al. (2010), which also rely on ANT but otherwise develop their "energy cultures framework" strongly on the basis of Lutzenhiser (1993) cultural model of household energy consumption. Interpreting ECB as interactions between cognitive norms (e.g., beliefs, understandings), material culture (e.g., technologies), and energy practices (e.g., activities and processes), Stephenson et al. could be read as merging types one and three. However, there are obviously some important caveats. First, there is a gap between economics and the other types. Second, all rely on some disciplinary, partly contested theory. Third, governance of change is often only represented by the very general category "intervention," leaving it as a black box.

Indisputably and again following Wilson and Dowlatabadi (2007), an interdisciplinary framework should succeed in integrating the best conceptual and empirical basis already created by scholars within the contributing disciplines. To cope with this requirement, we want to look at the existing state of the art in the disciplines we represent, i.e., psychology, economics, consumer behavior, business science, sociology, and political science. We shortly present their basic findings and major existing knowledge gaps in the following.

ECB and its Change from a Psychological Perspective

Psychology differentiates between single-shot energy-related decisions (such as purchase of energy-efficient appliances) and everyday energy-related behaviors such as showering behavior or commuting that are, to a larger extent, characterized by automatic habits and routines, and may thus be differentially influenced by psychological factors (Breukers et al., 2013). Psychological approaches in general emphasize the importance of factors such as belief structures, value systems, attitudes, emotions or social norms on energy-related decisions and behaviors (Ajzen, 1991; Stern, 2000). The Theory of Planned Behavior (TPB, Ajzen, 1991) assumes that decisions and behaviors are the consequence of a process that weighs the costs and benefits of the behavior, taking into account the factors *attitude* toward the behavior, perceived behavioral *control* and *norms* held by important reference people. TPB has been successfully used to predict a wide range of behaviors, including energy-relevant behaviors such as energy savings (Harland et al., 1999) or choice of transportation (Bamberg et al., 2003). As a "rational choice"-theory, TPB conceptualizes individual decisions as driven by cognitive processes underlying self-interested utility maximization. Value-Belief-Norm Theory (VBN, Stern, 2000) has been developed with the aim to explain altruistic behavior. VBN proposes a causal mechanism focused on individual *core values*. These values are broad representations of an individual's overarching goals that guide the evaluation and selection of behaviors in many different contexts (Rohan, 2000). Different value bases may drive energy-saving behavior: *self-interest values* may lead to energy-saving behavior because of the consequences for one's own well-being, a perspective consistent with the economic rational actor model; *social altruism values* refer to concerns about a larger circle of individuals, possibly extending to all mankind; *biospheric altruism values* refer to concerns about all living species and the state of ecosystems, beyond the potential benefits to human life. VBN has been used to successfully predict a number of energy-relevant decisions and behaviors, such as intentions to reduce car use (Nordlund and Garvill, 2003) or to recycle (Guagnano et al., 1995). Recent research has furthermore investigated the role of *emotions* in energy-relevant behavior, illustrating that an individual's emotional reactivity in environmentally relevant situations is a good predictor of intentions to reduce energy use (Brosch et al., 2014).

Furthermore, psychological theories take into account that individual energy consumption is shaped by its social context. This is of particular relevance when explaining behavior change. Social influences on changes regarding energy consumption patterns were demonstrated empirically for different types of energy services. For example, a series of field experiments in California indicates that household electricity consumption can be reduced by providing households with feedback about their own consumption and about the average consumption in their neighborhood (Schultz et al., 2007). Two different types of social norms have been shown to be important for promoting electricity savings; descriptive norms (i.e., feedback about average consumption in the neighborhood) and injunctive norms for preventing below-average consuming households to increase consumption (i.e., evaluation of own consumption relative to neighborhood consumption by means of the icons ϑ or Λ). The mentioned effects could be replicated in different studies, and the effects have shown to be long-lasting (up to 12 months, Ayres et al., 2013). Thus, energy consumption feedback including a social, competition-like situation seems to be a very promising approach (see also Abrahamse et al., 2005). In the domain of transport, an important determinant of individual bicycle use is the existence of a cycling culture within the community; the more people use bicycles, the more attractive this behavior is also for other individuals (Goetzke and Rave, 2011). Reasons for this are informative (e.g., people see each other cycling and talk about the benefits) but also normative (e.g., norms that cycling is healthy and ecofriendly, conformity pressure).

From a psychological perspective, ECB represents the result of a complex interplay between individual factors such as attitudes, values, emotions, and know-how, as well as social rules and norms. Accordingly, psychological approaches should be complemented by other disciplines in order to contribute insights for ECB. Close interdisciplinary collaboration is needed to fill the following research gaps:

- understanding the complex interplay of psychological, socio-demographic/economic, and spatial factors to explain energy-related decisions and behavior (further necessary disciplines: sociology, geography);
- analyzing the most promising interventions to change

behavior in terms of energy-saving potentials and social acceptance (further necessary disciplines: behavioral economics, sociology, environmental engineering);
- linking the governance and the individual level when designing interventions to change individual level (further necessary disciplines: policy sciences).

ECB and its Change from an Economic Perspective

In accordance with standard consumer theory, the analysis of ECB in economics starts from the assumption that individuals or households choose their demand for energy services as part of a consumption bundle that maximizes their utility subject to budget and information constraints. Energy services are produced by the households using capital and energy inputs. Observable demand for energy inputs such as gas, oil, or electricity is therefore "indirect" in the sense that it is not only based on preferences and constraints, but also on available technologies that convert energy inputs into energy services. An important notion of the general equilibrium theory that informs economic analysis is that changes in determinants of behavior automatically lead to adjustments in behavior. For this reason, economics lacks a stringent differentiation between determinants of behavior and determinants of behavioral change.

Following the discipline's strong focus on constraint-based explanations of consumer behavior, empirical research into energy consumption has focused overwhelmingly on the effects of prices and income. It has demonstrated that variation in energy prices accounts for a substantial share of variation in demand. Moreover, it has shown that long-term adjustments to price changes (i.e., price elasticities) are substantially larger than short-term adjustments, suggesting that energy prices are important determinants of investment decisions into energy efficient household appliances and home improvements (e.g., Khazzoom, 1987; Durham et al., 1988; Van den Bergh, 2008). Accordingly, price-based instruments (taxes, subsidies, differentiated rates) are considered to be the most effective and efficient policy measures to achieve socially optimal energy use patterns (Gillingham et al., 2009; Linares and Labandeira, 2010; Gillingham and Palmer, 2014). Similarly, research suggests that information provision can help in improving consumer decisions with respect to direct energy demand (Abrahamse and Steg, 2009) and investment in energy-efficient household appliances (Deutsch, 2010; Heinzle, 2012; Ölander and Thøgersen, 2014).

Other, less conventional factors of energy demand like social considerations, pro-environmental attitudes, risk aversion, or feelings of guilt have been incorporated into the utility approach by assuming that they can be modeled as arguments in the individual's utility function (Kotchen and Moore, 2008; Jacobson et al., 2012; Lange et al., 2014). Differences in incentive structures have also been identified as barriers to socially optimal energy demand. For instance, it has been shown that owners and renters differ substantially with respect to energy use and investment in energy-efficient durables (Davis, 2012; Gillingham et al., 2012). Finally, a wealth of recent research has demonstrated that decisions on energy use are partly driven by automatic and unconscious processes like preference learning, time inconsistencies, framing effects, and decision heuristics, which contradict the assumption of a consistent utility-maximizing individual (Sunstein, 2015; Pollitt and Shaorshadze, 2013; Ölander and Thøgersen, 2014).

While the economic approach to household energy demand has been widely successful in explaining patterns of price and income effects, less progress has been made in understanding determinants of behavior and behavioral variation beyond variations in budget constraint and information. Integrating theories and findings from other disciplines may, thus, substantially improve our understanding of household behavior and may shed light on important interactions between economic and non-economic determinants of energy demand. Such insights may help to address some of the following research gaps:

- understanding the considerable variation in household responses to economic policy incentives, such as subsidies for energy-efficient retrofits, differentiated tax rates, social nudges, or energy labels;
- extending the analysis of social reward and social comparison mechanisms in determining energy consuming behaviors and the adoption of innovations;
- investigating the interactions between intrinsic motivations, social nudges, and economic policy incentives in households' energy-conservation efforts. Specifically, understanding the conditions under which policy incentives and social nudges reinforce rather than undermine intrinsic motivations;
- complementing the empirical analysis of household energy demand by accounting for the indirect energy embodied in the supply chain of products and services consumed by the household;
- evaluating the effectiveness of different energy conservation policies considering the complex interplay between direct and indirect energy demand. This is particularly important for a comprehensive understanding of the long-term consequences of efficiency-induced income expansions or savings (e.g., rebound effect).

ECB and its Change from a Consumer Behavior Perspective

Thriving as an independent field at the interface between behavioral economics and psychology, Consumer Behavior has originally emerged as a sub-discipline of marketing. At its core, it involves "*the study of people operating in a consumer role involving acquisition, consumption, and disposition of marketplace products, services, and experiences*" (MacInnis and Folkes, 2010). Being a multidisciplinary field that encompasses perspectives and blends elements from a multitude of different disciplines, including economics, sociology, political science, and others, academic research in the consumer behavior field has further developed from limiting its focus to marketing management to also taking a broader angle by integrating a societal and public policy perspective that also involves examining consumers' choices outside the conventional company–customer purchase context (MacInnis and Folkes, 2010).

The consumer behavior field has seen the emergence of many different specializations. One of the sub-disciplines is the *Behavioral Decision Theory* that deals with, among other things, heuristics and biases (MacInnis and Folkes, 2010). The starting point of this research stream is that in reality, consumers often simplify their decisions by relying on decisions strategies that can be described as simple "rules of thumb" (Thaler and Sunstein, 2008). Heuristics often speed up the decision-making process and produce sensible judgments and behavior. However, applying heuristics can also lead to systematic errors, or so-called "cognitive biases." Classic specific cognitive biases include framing effects, loss aversion, *status quo* biases, or hyperbolic discounting, just to name a few. Research on heuristics and biases can noticeably contribute to a better understanding of the energy-conserving behavior of consumers. For instance, research on the *status quo* effect has shown that when consumers are presented with a utility bill that contained a default choice, most consumers would be reluctant to change it (Brennan, 2007). In a similar vein, McCalley (2006) showed that the default setting of the washing machine leads to significant differences in the energy used. In addition, research on heuristics can also contribute to the long-standing debate about the commonly cited "energy efficiency gap." Many scholars have investigated measures to limit this gap, including the introduction of energy labels or providing information with regard to future operating costs (e.g., Kaenzig and Wüstenhagen, 2010). Nevertheless, research related to framing has revealed that not only the provision of such information but also the framing of such information (e.g., design of energy labels) impacts decision-making (e.g., Heinzle, 2012; Heinzle and Wüstenhagen, 2012; Meissner et al., 2013; Ölander and Thøgersen, 2014).

In another specialization of consumer behavior research, different scholars studied characteristics of eco-conscious consumers including demographics, psychographics, and behavioral variables (e.g., Straughan and Roberts, 1999; Do Paço and Raposo, 2009). In addition, there is a vast amount of literature in the consumer behavior field devoted to examining the effectiveness of softer motivators applied by social marketers to foster energy conserving behavior, including social norms, commitment strategies, prompts, or soft nudges (e.g., Aronson and O'Leary, 1982; McCalley, 2006; Goldstein et al., 2008; Schäfer et al., 2012; Baca-Motes et al., 2013; Burchell et al., 2013; Sunstein and Reisch, 2013). Other streams of research are devoted to analyzing new less resource-intensive models of consumption such as collaborative consumption (e.g., Botsman and Rogers, 2010; Belk, 2010; Ozanne and Ballantine, 2010; Bardhi and Eckhardt, 2012) and the relationship between materialism and happiness (e.g., Burroughs and Rindfleisch, 2002). Last but not least, another field of research is devoted to analyzing possible side effects of adoption of single energy conserving behaviors, including positive spill-over effects or moral licensing (e.g., Tiefenbeck et al., 2013). There is clearly a need for further research in this area to determine (a) whether evidence for moral licensing is widespread in different contexts and (b) whether the effect is only a short-term phenomenon.

Despite being already a multi-disciplinary field, consumer behavior research could collaborate with other disciplines in order to contribute to a more comprehensive understanding of consumer behavior related to energy conservation. For instance, cooperation would be fruitful in order to contribute to the subsequent research gaps:

- investigating the role of the effectiveness of governmental incentives and new financing models (e.g., leasing) in order to address the energy efficiency gap (collaboration with disciplines: finance and political sciences);
- investigating the role of social approval motivations and the effectiveness of social rewards (e.g., free use of bus lanes with electric vehicles) regarding the adoption of innovations (collaboration with disciplines: psychology and sociology);
- investigating the role of computing and information technology to reduce energy consumption (collaboration with disciplines: information and computing technology);
- investigating the role of misleading green claims on consumers' trust to purchase green products and designing effective interventions/laws to reduce green-washing (collaboration with consumer law);
- better understanding of adoption of innovations by visualization of peer effects (collaboration with disciplines: geography and sociology);
- better investigation of the information processing effected by the brain related to heuristics and biases (collaboration with disciplines: psychology, behavioral economics, and neuroscience).

ECB and its Change from a Business Science Perspective

The business science is more focused on the energy consumption of businesses than that of individuals. As a result, the literature is rather scarce on the impact of businesses and managerial decisions on ECB, especially in terms of integrative models or theories. The relevant literature can be structured in three main disciplines: marketing, innovation management, and operations research.

First, marketing is by nature more interested in changing or maintaining behaviors than in explaining behaviors (the latter is covered by the consumer behavior perspective). Marketing research on energy conservation programs highlights the importance of making transparent the information about price (Rudelius et al., 1984), the lack of data on energy consumption that limits the programs' effectiveness (Hirst, 1980), the need to segment the market and how to do it (Allen et al., 1982; Downs and Freiden, 1983; McDonald et al., 2012), as well as factors that prevent sustainable energy consumption, categorized into policies and regulation, product accessibility and availability, pricing, and customer knowledge (Press and Arnould, 2009). Those researches are usually relevant for public or non-profit organizations that design marketing programs to stimulate energy conservation and, in specific situations, for private companies [see for instance Harvey and Kerin (1977)].

Second, innovation management research has investigated ECB mostly through cluster management, product design, and diffusion of innovation. Similar to marketing, research on innovation management has analyzed the impact of innovation-related decisions or actions on change in energy-related behaviors rather than on explaining those behaviors. For instance, innovation centers play an important role to reduce energy consumption in cities (Foley et al., 2011; Baydoun, 2013). Innovation management research also shows that innovative product design and design process have indirect effects on individuals' consumption (Cainelli and Mazzanti, 2013; Favi et al., 2014). For instance, Shrestha and Kulkarni (2012) find that product design (using the case of homes and appliances) needs to take into account homeowners' lifestyle and comfort level to reduce energy consumption levels more effectively. Studying the role of sustainability initiatives, Susskind (2014) finds that subtle in-room energy reduction does not decrease consumer satisfaction. This highlights the potential for businesses to reduce individuals' energy consumption through service design while incurring a cost benefit without depreciating satisfaction. Finally, energy-efficient innovations are usually not enough to reduce ECB (Herring and Roy, 2007). Innovations and a better understanding of the factors of their adoption as well as the promotion of sustainable lifestyles must be combined to avoid rebound effects.

Third, operations management research related to ECB has rather focused on demand forecasting (modeling demand) than on how to reduce demand (changing demand). For instance, energy demand models have been developed in the natural gas (Brabec et al., 2008) or electricity sectors (e.g., Charlton and Singleton, 2014; Haben et al., 2014). However, some research also highlighted possibilities to reduce consumption: Loock et al. (2013) highlight how information systems can stimulate individuals' energy conservation through the use of a goal setting functionality, default goals, and a feedback mechanism.

Although some researchers have investigated the impact of organizations on ECB from a business or managerial perspective, there are gaps in the literature, many of which require cooperation across disciplines to be filled. Examples of gaps and potential for cross-disciplinary collaborations include the following:

- understanding the overall impact of businesses and managerial decisions on ECB, in particular related to embodied energy (economics, psychology);
- understanding business influence to changes in ECB. Concepts such as the circular economy (see for instance SATW, 2014), service co-production (Auh et al., 2007), and corporate social responsibility initiatives to reduce individuals' energy consumption could foster innovative ideas as they hold potential to also benefit companies (economics, psychology, sociology);
- understanding governance mechanisms and incentives that stimulate businesses to reduce energy consumption at the household level (political science, economics).

ECB and its Change from a Sociological Perspective

If we understand the use of energy services as consumption, three sociological ways of studying ECB may be identified. The first strand conceives of consumption as a means to express identity, often within a post-structuralist framework (e.g., Bauman, 2001). Work in this strand centers around what came to be called the "communicative paradigm" (Soron, 2010, p. 175), which is interested in the symbolic meanings of consumption. ECB is explained as being rooted in shifting modes of how people construct their identities in individualized and consumerist societies. A second strand conceptualizes consumption as a moment of practice that reproduces hierarchies and acts as a marker of milieu membership (Bourdieu, 1979; Giddens, 1991; Veblen, 2007). From this perspective, factors of energy consumption are milieu or class specific consumption patterns that are shaped by the distribution of various resources and embedded in practices. A third strand revolves around different adaptations of rational choice theory (RCT; Coleman, 1986). RCT has been employed by various disciplines to investigate behavior that is relevant to sustainability and the use of energy services. Here, ECB is an outcome of people trying to maximize utility functions. This approach is fruitful when the aim is to develop causal explanations of micro level behavior and its effects on the macro level (Lovett, 2006; Liebe and Preisendörfer, 2010).

In the context of this paper, the second strand appears to be most relevant as it implies looking at how high level structures affect low level structures and vice versa while allowing for a rich contextual understanding of energy consumption. This approach aims to balance structure and agency by looking at how the distribution of various resources, such as economic capital and knowledge, affect individual energy consumption and thus the potential to attain well-being (Jackson, 2005). A basic assumption is that consumption creates identity, distinction, and status (see Bourdieu, 1979). Various processes, however, such as falling prices through productivity gains, diminish the distinctive power of food and appliances (Thøgersen, 2005). Hence, people consume more and more exclusive products to distinguish themselves from others. Every-day routines without much distinctive power, for example taking a shower, also prove to be important drivers of energy consumption (Jackson, 2005). An important body of literature emphasizes the relevance of these inconspicuous routines and habits to consumption patterns (Southerton et al., 2001; Shove, 2003). Consumer culture and "keeping up with the Joneses dynamics" lead to more resource intensive standards of living (Southerton et al., 2001). ECB is then understood as a moment of social practice and changing ECB will require transforming social practices (Warde, 2005; Walker, 2014).

Yet, there have been no attempts to systematize and conceptualize energy relevant routines and conventions of individual energy consumption patterns and its change in the sociological literature. To advance the sociological understanding of ECB and its change, insights generated by other disciplines are necessary to:

- elucidate the level of the individual, e.g., the social consequences of breaking habits via disruption and the effects of financial incentives (psychology, economics);
- understand how modes of governing energy behavior may affect societal structures and their incumbents, e.g., through transformations of contextual factors that may shift practices (political sciences).

Governance of ECB from a Political Science Perspective

Political science is not concerned with explaining individual behavior, but steering individual behavior and its change are important issues. However, in the field of energy policy research, most analyses focus on the aggregated societal, economic, environmental, and technological effects of certain energy policy schemes (e.g., Lewis and Wiser, 2007; Lipp, 2007; Carley, 2011; Delmas and Montes-Sancho, 2011). Only a few contributions are specifically concerned with the political steering of ECB (e.g., Lindén et al., 2006; Owens and Driffill, 2008; Gyberg and Palm, 2009). In any case, the development within the discussion on political steering needs to be taken account of in research on governance of ECB.

The classical literature pertaining to political steering focused on the analysis of the design and implementation of policy instruments as well as their impacts and outcomes (Hood, 1983). Successful steering was mainly seen as a matter of rationally designing policy instruments that affect the behavior of collective (firms, organization, groups) and individual actors according to a set of steering goals defined by the state. This has yielded a differentiated understanding of the functioning of various types of policy instruments – "carrots, sticks, and sermons" (Bemelmans-Videc et al., 2011) – as well as of their general effectiveness and efficiency (Vedung, 2007). However, this focus on state defined policy instruments became questioned. First, the dominant rationality assumption turned out to be flawed. Empirical studies showed that the design and implementation of policy instruments and thus their success and failure were affected by multiple contextual factors, such as power relations, values, beliefs, acceptance etc. (Linder and Peters, 1989; Schneider and Ingram, 1990; Howlett, 1991; Hill and Hupe, 2002). Second, the steering paradigm was criticized for its unrealistic division between the state (steering subject) and the society (steering object). Empirical studies showed that there are also societal actors who actively shape the goals and means of steering (Mayntz et al., 1978; Bardach, 1979; Sabatier, 1986). Finally, advocates of liberalism argued that the steering deficits were in fact "government failures" and opted for regulations on grounds of market principles. Moreover, participatory democrats interpreted the steering failures in terms of "democratic deficits," and thus called for the empowerment of citizens and the establishment of community-based settings of "self-help" (for energy-related issues, see, e.g., Kellett, 2007).

These criticisms gave rise to a more fundamental paradigm change in steering theory (Eliadis et al., 2005). The new "governance" concept rejects the idea of an omnipotent state, which rationally designs and implements policy instruments in a top-down manner. And it questions the adequacy of both the liberal and participatory alternative. Political steering is seen to involve state, market, and societal actors who set and coordinate their individual action courses in complex settings of different governance mechanisms. It is neither pure state hierarchies, nor liberal markets or citizen communities that organize collective action, but context-specific mixes of them (Salamon, 2002; Pierre and Peters, 2005; Howlett, 2009, 2011). From this perspective, steering societies is about the design of complex governance arrangements by combining elements of policy, politics, and polity[2] in a systematic, but problem-related manner (Lange et al., 2013; Voß et al., 2006).

Whereas the "governance turn" in steering theory came with a focus on the organization of *collective* action, the "individual" has recently been re-discovered in political science, especially under the term "nudging" (Thaler and Sunstein, 2008; Jones et al., 2014). The core of this idea is to shape the behavior of individuals without normatively forcing, economically stimulating, or morally pushing them. Instead of using visible "carrots, sticks, and sermons," individuals are addressed with invisible "nudges": unconscious modulations of their choice architectures. "Nudging" broadens the range of options for steering individual behavior based on the latest insights in behavioral sciences. However, apart from the need for further conceptual (Selinger and Whyte, 2012), normative (Vallgårda, 2012; Fischer and Lotz, 2014), and functional reflections (Schnellenbach, 2012), the discussion seems to fall back behind the insights of the governance turn in steering as it tends to neglect the embedding of nudges in complex institutional and procedural settings.

Against the backdrop of the developments in the general discussion about political steering, there are good reasons to frame the challenge of steering ECB in terms of a governance perspective. Governance of ECB is about the design of complex governance arrangements: institutional settings in which multiple actors coordinate their multiple policy interventions. In light of this basic understanding, two routes seem to be of particular relevance for a collaborative research agenda on the governance of ECB:

- the governance perspective broadens the focus on "instruments," which is prevalent in the other disciplines related to ECB and highlights the need for an embedded analysis of these instruments;
- to better understand the functioning and impact of complex governance arrangements on ECB, political science would benefit from the insights of the other disciplines with regard to the multiple factors that determine ECB and its change.

First Synthesis: Categories, Gaps, and Challenges

Obviously, there are both a rich body of scientific knowledge as well as a remarkable amount of knowledge gaps. The next step in developing a framework consists in trying to substantiate what has been sketched such that we can see in what respect the different disciplines provide answers to the five stated questions. In addition, it is also of interest to capture the different desiderata mentioned within the state of the art's descriptions. In what follows we restructure the given descriptions along first their answers to questions (1) and (3) (expressing the two objects of explanations, i.e., the explananda; cf. table 1), then second their answers to questions (2) and (4) (expressing the candidates for explaining the behavior and its change in questions, i.e., the explanantia; cf. table 2), and finally the answers on question (5) (cf. table 3).

(1) & (3): political science does not contribute to explaining behavior but only to its change (**Table 1**). The other disciplines often refer to "energy services"; however, there are obviously some variations and different foci. It is far from being evident that "decisions," "demand," and "use" have the same meaning. They could well express different aspects of the behavior. Many studies in the field still do not operationalize "use of energy services" for their research and only look at the amount of used primary energy [for a discussion on this, see Jonsson et al. (2011)]. Moreover, analyses of ECB often focus on specific sectors of direct use such as electricity, thermal energy for housing, and fuel energy for transport.

[2]Political science distinguishes among these three dimensions, i.e., "polity" as political structures, "politics" as procedures and "policy" as contents (e.g. March and Olsen, 1983; Schubert and Klein, 2011).

Energy consumption patterns within domains of "embodied" or indirect energy use such as food, clothing, leisure activities etc., are analyzed to a lesser degree. This has been highlighted several times. Collecting the main elements given above, we can gain the following picture regarding questions (1) & (3).

In addition, the literature contains more detailed distinctions concerning (1) & (3). One can find, for example, purchase or investment compared to daily application (instead of single-shot and routines, cf. Breukers et al., 2013). Bergius (1984) classifies material-specific (e.g., purchase) and action-specific (e.g., usage) behavior; Van Raaij and Verhallen (1983) distinguishes between purchase, usage, and maintenance behavior. Further criteria for characterizing the explanandum can be areas of life (home, work, spare-time) or starting points for energy saving behavior. Some approaches explicitly take "environmental friendly" behavior as expressing our "change of behavior" (Wilson and Dowlatabadi, 2007). Obviously, we need not only to distinguish between "explaining behavior" and "explaining change of behavior," but also we also need to establish a precise common understanding of what we want to explain.

(2) & (4): collecting and structuring the proposed explanantia as well as considering the desiderata addressed above, we achieve again a complex and multi-variant picture (**Table 2**): first, Political science does not offer explanantia as they are not analyzing behavior. They contribute to governance related factors to be captured in **Table 3**. Second, there are again some disciplinary overlapping or similarities but also differences. Each discipline refers to a set of explaining factors that include mental (e.g., decision heuristics) and some sort of social factors (e.g., norms). This is fully in line with Darnton (2008) who argued that understanding the dynamic of consumption transcends a division between internal (mental) and external (societal) factors. Some of these factors like emotions, however, have only been included rather recently in research agendas. And though the disciplines have their foci such as income or decision heuristics, they also strive to consider the interplay with other factors. Exciting research desiderata are mainly identified regarding our understanding of how the different factors interact. Third, business science, consumer behavior, and sociology point to social segmentation as a potentially explaining factor, whereas the economists refer to unexplained variations in behavior. In what

TABLE 1 | Explananda in the foci of the different disciplines.

	Psychology	Economics	Consumer behavior	Business science	Sociology	Political science
Question (1): explanandum "ECB"	Single-shot energy-related decisions and routines; rational (utility oriented) and altruistic behavior	Demand for energy services; part of consumption bundle; maximizing utility	Acquisition, consumption, and disposal of products, services, experiences	Demand for energy (forecasting purpose)	Use of energy services; ECB as a moment of practice	N/A
Question (3): explanandum "change of ECB"	Change of individual behavior or decision patterns	Reducing overall individual consumption	Change of individual consumer behavior	Change of consumer behaviors; reduction of embodied energy in products and services	Change as transformation of practices	Change of individual behavior in light of collective goals
Desiderata	Better understanding the complex relations of psychological, socio-demographic/economic, and spatial factors	Focus on single sources like electricity; embodied energy missing	Considering potential side effects of behavior change in single domains (e.g., spill-over effects, moral licensing)	Considering embodied energy in products and services	No systematic approaches to individual energy consumption patterns and its change in sociology	

TABLE 2 | Explanantia in the foci of the different disciplines.

	Psychology	Economics	Consumer behavior	Business science	Sociology	Political science
Question (2): explanantia for explaining ECB	Belief structures, value systems, attitudes, emotions, social norms; complex interplay between individual factors and know-how, as well as social rules and norms	Prices and income; social considerations, pro-environmental attitudes, risk aversion; differences in incentive structures; unconscious processes (e.g., preference learning)	Characteristics of eco-conscious consumers (incl. demographic, psychographic, and behavioral variables), heuristics, and related biases in decision-making	Prices, seasonality, consumer profile, consumer past demand, etc.	Symbolic meanings; distinction, status (hierarchies, classes, milieu); practices, habits, routines; distribution of resources; maximization of utilities	N/A
Question (4): explanantia for explaining change of ECB	Changed values, norms, attitudes etc.	Changed prices, incentive structures; dealing with and using decision biases etc.	Changed values, norms, attitudes, access to information, pricing, etc.	Market segmentation; product accessibility/ availability, pricing, etc.	Changed symbolic meanings or identities or routines etc.	N/A
Desiderata/ interfaces	Knowing interplay of psychological, socio-demographic, and spatial factors	Understanding behavioral variation beyond the variations in budget and information constraints	Better understanding of the effectiveness of governmental incentives, social marketing, innovative financing models, etc.	Understanding how businesses affect part of ECB and how these business factors interact with others	Intra-individual processes, effects of governance	N/A

TABLE 3 | Governance in the foci of the different disciplines.

	Psychology	Economics	Consumer behavior	Business science	Sociology	Political science
Question (5): governance of change of ECB	Tailored interventions, social feedback; descriptive and injunctive norms; social culture; nudging	Price-based instruments; overcoming biases and using biases	Policy instruments and social marketing campaigns	Social marketing strategies and tactics; product and service innovations	Interaction between action of individuals and social structures, feedback loops	Multiple policy instruments with different steering potentials
Desiderata/interfaces	Understanding the interplay of the factors	Integrating socio-economic and psychological determinants	Understanding the impact of the different explanantia on change	Integrating cross-disciplinary insights into marketing strategies; understanding potential for increasing competitiveness through change	Linking sociological approaches to insights on explanantia from e.g., psychology and economics	Identification of access points for political steering; understanding the interplay of multiple factors

respect social segmentation and lifestyle aspects have an impact on ECB and its change, however, has so far not been systematically addressed (e.g., Barr and Gilg, 2006; Stephenson et al., 2010). Finally, there are not many differences between factors explaining the behavior and the factors for explaining its change on the level of abstraction we are dealing with here. If values are an explaining factor of ECB, then values will also function as an explaining factor in changing the behavior. The difference in behavior will result from a difference in the value set. Following this line, we get the following answers regarding questions (2) and (4).

(5): governance: the last question concerns the constituents to be taken into account in steering change of ECB (**Table 3**). Such changes are purposely brought about by some steering activities mostly against the backdrop of considering public goods and directed on certain factors in (4).[3] The spectrum of related candidates given covers the whole range of policy instruments as well as social and market interventions. From an economic perspective, price-based instruments (taxes, subsidies, differentiated rates) and legal regulations are considered to be the most effective policy measures. Psychology as well as sociology points to reflective or competition-like feedback based factors in daily life, business science to new products and services, etc. Collecting again the main elements given above by the disciplines, we gain the following picture regarding question (5).

Obviously, there is again variation regarding, for example, the level of change (individual, organizational, and systemic) but also regarding the scope of governance, for example, covering only the governmental or also the civil society side. In addition, all disciplines point to different loose ends that need to be filled in collaboration with other disciplines.

Against this backdrop, we are tempted to summarize the current state of the art as follows: there is only partial knowledge on what forms of governance induce which changes in what kind of energy-related behavior of which individuals. One important reason for this situation is that the manifold of factors to be explained – be it consumption or be it change of behavior – or for explaining ECB and its change are only partly linked systematically. An integrated framework could allow doing this in a systematic way.

[3]The existing ECB is already an effect of multiple steering efforts within different governance arrangements. Steering change of ECB can also be read as changing governance arrangements.

An Integrated Framework

There are no strict borderlines between models and frameworks and both terms are used in a variety of ways (cf. Frigg and Hartmann, 2012 on models). Here, we refer to the following distinction: while a model tends to be object-specific and explanatory, a conceptual framework provides a rather general descriptive foundation for explanatory inquiries. Accordingly, it does not provide explanations by itself, but frames the space for searching for explanations. Moreover and in contrast to the frameworks presented in Section "Paving the Way Towards an Integrated Framework (Relevance And Gaps)" above, we refrain from building the framework onto a specific theoretical fundament. Searching for such a common theoretical basis is an unrealistic endeavor given the manifold of theoretical behavior approaches, e.g., rational choice, bounded rationality, theory of planned behavior, norm-activation-model, value-belief-norm characteristics, social practice theory etc. (cf. Keirstead, 2006; Wilson and Dowlatabadi, 2007; Darnton, 2008; Stephenson et.al, 2010; Karatasou et al., 2014). Accordingly, the framework is problem oriented, not theory oriented.

In addition, Darnton (2008) draws our attention to some specific challenges. First, a framework should display a reasonable balance between simplification and comprehensibility, i.e., neither abstracting from too many factors that characterize a situated individual, nor trying to include as many factors as possible. Second, the scope of a framework is restricted to what has been framed as belonging to the explanandum (see Section "Problem Statement"). If the explanandum is "environmentally friendly behavior," the according framework could be different in comparison to "ECB." Third, the distinction between explaining behavior and explaining change of behavior has to be captured. Finally, a framework on ECB should include social structuration and not to go along an abstract type of consumer (everyman-models).

We will proceed as follows to serve all the stated requirements: we will frame the explananda (what has to be explained) in a first step, hence approaching question (1) regarding ECB and question (3) regarding its change. The second step concerns the explanantia, taking up questions (2) and (4) on the factors that explain the behavior and its change respectively, by introducing the categories "Opportunity Space" and "Decision-Making" as well as an approach for social segmentation. The third step would then deal with the governance aspects, related to question (5). The thus composed framework is based on the results of the disciplinary reviews.

However, it also goes beyond them by relating and integrating them within an interdisciplinary framework.

Explananda: Types of ECB and Their Change

When talking about ECB, it seems to be tempting to envisage the consumed energy, expressed in some kJ/individual, as the object of analysis. However, no discipline goes along that line. Instead, it has become standard to talk in terms of "energy services." The latter takes into account (1) that individuals generally consume goods and services, i.e., do not use energy directly, but are demanding services like a heating system that (2) serve specific benefits expressing subjective well-being like having it nice and warm. Turning the heating on is connected to coziness and health, using the car is often associated with comfort and convenience etc. (Shove, 2003). The last example adumbrates, however, that the associated underlying expectations regarding well-being could differ remarkably across the individuals.

Bergius suggested distinguishing between action-specific and material-specific ECB (Bergius, 1984). Another option is to distinguish between using and purchasing. We follow Bergius here by integrating the latter into it. Lighting, cooking, driving by car, and watching TV are examples for action-specific ECB accompanied by some energy consumption. In contrast, material-specific ECB are normally purchasing activities that do not include any direct energy consumption. However, there is already a notable amount of energy consumed for production and transportation of the products when looking at the whole life cycle of a product: embodied energy. Embodied or material-specific ECB not only concerns energy-related goods, such as washing machines, light bulbs, or heat pumps, but also all kinds of consumable products, i.e., soft goods as food, apparel, cosmetics, paper products, personal products, as well as hard goods like furniture, sports equipment, toys, etc. By further distinguishing the main consumption domains "heating," "electricity," "mobility," and "consumption of products," we get to the table in **Figure 1**. The categories within the frame display our answer to the first question. The examples indicate possible exemplifications.

Although material-specific ECB is often "single-shot-behavior," some purchase activities especially in the field of consumption of products can become habits and routines. And although action-specific ECB is very often dominated by routines, there are cases of single shots in that field as well (e.g., realizing some specific traveling). Hence, a specific behavior is either single-shot or habit/routine. In addition, the relation to "well-being"/quality of life is included by definition in "demand of energy services." But taking into account that it is a non-observable part of the behavior, it is not explicitly specified in **Figure 1**.

There seems to be a straightforward answer for question (3) on "what is change of ECB": the amount of reduced energy like some ΔkJ/individual or some ΔTJ on an aggregated level. Following our line of reasoning, however, this can hardly be the explanandum because individuals do not consume energy but energy services. "Change of ECB" means changed demand for energy services. The explanandum could therefore encompass any feature within **Figure 1** including changed expectations toward "demands" and thus quality of life. Notwithstanding the envisaged reduction goals, the general components from question (1) remain the same. It is still ECB we are looking at. Two additional components need to be included to cope with the fact that we are talking about change: the time factor and the societal goal in question. Accordingly, our second explanandum (a) consists in the same categories as in **Figure 1**, including (b) a time factor, and (c) variations in demand of energy services that are expected to contribute to achieving the reduction goal.

Reducing energy consumption means in general changed demand of energy services or products either on the action

Action-specific / Direct	E.g., heating, using warm water	E.g., cooking, washing, watching TV, listening to music, turning lights on, using air conditioning	E.g., driving, using plane	E.g., skiing, going out for a meal
Material-specific / Embodied	E.g., purchase specific heating units, boiler, heat pump	E.g., purchase specific washing machine, TV, pc, mobile, light bulbs, air conditioner	E.g., purchase specific car	E.g., purchase leisure equipment, soft goods (food, apparel), hard goods (furniture)
Demand of Energy Services	**Heating**	**Electricity**	**Mobility**	**Consumption of Products**

FIGURE 1 | **Explananda – examples for types of ECB.**

or the material-related side. Material-related improvements cover, for example, increased efficiency in terms of replacement of existing appliances, goods, and services by more energy-efficient ones (e.g., purchase a new A+++-rated refrigerator or a fuel-saving car). Action-related improvements primarily comprise changes in the use of energy services, e.g., the renouncement of some energy consuming activities or its substitution by the use of less energy-intensive services (in the sense of sufficiency strategies). For example, individuals can alter their heating and ventilation habits, can renounce using specific appliances, can cycle instead of drive, and can consume less energy-intensive products, e.g., eat less meat. Moreover, there are two rather new phenomena. Material-related improvements could also comprise "prosumer" activities: energy consumption reduction in terms of self-generation of energy or products. Moreover, there is "outsourcing" the consumption, especially by substitution of personal property and use of shared services instead. **Figure 2** indicates a number of options leading to changed demand, even though disentangling action- and material- specific behavior is not always straightforward especially in the field of products.

The domain of "changes" then also includes changed expectations regarding quality of life. Research has shown that people in the developed world like Japan, the U.S., or Europe have not become happier despite a massive increase in wealth (and directly related increase in energy use/CO_2 emissions) (Easterlin, 1995; Binswanger, 2006; Easterlin et al., 2010; Easterlin, 1974). Notwithstanding, there is also some evidence that income losses can have dramatic negative impacts on well-being (Boyce et al., 2013). Howsoever, the relation between energy services and well-being makes up an important field for research on change of ECB.

To sum up, we propose to frame the explananda – the individual consumption behavior and its change, respectively, as illustrated in **Figure 3**.

Explanantia: Explaining Energy Consumption Behavior and its Change

As we have seen in Section "Paving the Way Towards an integrated framework (Relevance And Gaps)," the disciplines offer a variety of determinants for explaining the behavior in question: psychology points to values, attitudes, emotions, while economics refer to socio-economic determinants such as income and prices, consumer behavior and economics to decision heuristics, and sociology to determinants like milieu, status, and inequalities. All disciplines contributing to explaining ECB stress the interplay between the different factors, and consumer behavior research is already an interdisciplinary endeavor (cf. Section "ECB and its Change from a Consumer Behavior Perspective"). The challenge for answering question (2) is not so much related to the factors themselves, as it is related to organizing them by taking account of explicitly not basing it on a specific theory (cf. above).

What we suggest here, is to organize the determinants against the weak background assumption that the consumer is an actor (agent). That assumption is weak in so far as we do not invest a specific actor theory. Nevertheless, the assumption is not "content-neutral," because there are some general features related to "being an agent." These features are in turn related to the rationale motivating our suggestion. There are always (either explicitly or implicitly hidden in routines) choices to be made (decision making) and there are always pre-conditions when talking about choices (the related opportunity space). The observable behavior (the above addressed explananda) results from explicit choices or routines on the basis of an existing opportunity space.

Against this backdrop, we suggest framing the realm of explanantia as follows: to capture the interplay between "the social" and the "individual" factors consistently pointed out by the disciplines (cf. Section "First Synthesis: Categories, Gaps and Challenges"), we use the term "situated individual" to highlight that we are looking at individuals living embedded in complex

Action-specific, Direct	E.g., reduced temperature in dwelling, changed heating and ventilation habits, showering instead of bathing, reducing shower time	E.g., renouncement of air-con, using appliances (e.g. laundry rack instead of dryer), turning off stand-by, changed cooking behavior	E.g., renouncement of using a car, using bike or public transport, driving behavior (eco-drive), reducing traveling by plane, choice of dwelling location	E.g., change of diet (e.g. eating less meat, less energy-intensive cooking), wearing second-hand clothes, reducing food waste, etc.
Material-specific, Embodied	E.g., increased building-related efficiency (isolation), purchase more efficient heating, own generation of heat (solar heat, heat pump), energy service contracting	E.g., purchase of more efficient appliances, energy-saving light bulbs, own generation of electricity (PV), energy service contracting	E.g., car sharing, purchasing more fuel-efficient cars	E.g., buying seasonal/ local/ organically produced food, purchasing eco-labeled cloths or furniture, own production of food
Changed Demand of Energy Services	**Heating**	**Electricity**	**Mobility**	**Consumption of products**

FIGURE 2 | Explananda – examples for types of changed ECB.

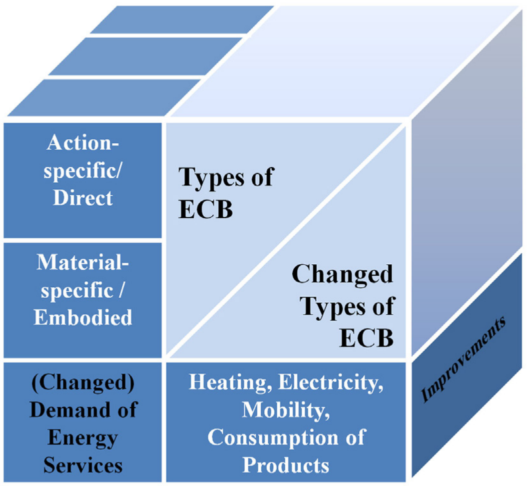

FIGURE 3 | **Explananda – types and changed types of ECB**.

social environments. The explicit choices or the routines leading to ECB of such a situated individual are then thought to be based on two major categories: the existing opportunity space and the individual's decision making.

Opportunity Space

There are two types of factors that make up an individual's opportunity space: factors on the macro-level expressing the social environment, and factors on the individual level. A distinguishing feature between them is that the former are normally not directly influenced by the individual, whereas the latter could be. An individual cannot change, e.g., the technological options as an individual, but she can try to change her educational or economic performance.

We label the structural elements framing the action fields for individuals on the macro level as belonging to the social opportunity space (SOS). SOS is thought to encompass factors such as [cf. Sections "ECB and its Change from a Psychological Perspective," "ECB and its Change from an Economic Perspective," "ECB and its Change from a Consumer Behavior Perspective," "ECB and its Change from a Business Science Perspective," "ECB and its Change from a Sociological Perspective," and "Governance of ECB from a Political Science Perspective"]): commercially available technologies or facilities, the economy in form of market structure, prices, the demography, existing institutions as norms, policies, and organizations, and culture (symbolic meanings). For example, if certain (energy-efficient) technologies are not commercially available, the options for changing the material-specific consumption behavior are restricted accordingly. Likewise, if there are legal norms constraining energy consumption, e.g., isolation norms for dwellings, the individual's behavior is shaped by such a norm. One might add geography and climate to include spatial factors (e.g., regarding settlements).

Contrarily, we name the many factors on the micro-level discussed by the disciplines above as belonging to the "individual opportunity space" (IOS): age, gender, and constitutional factors, material living conditions (housing, appliances, education, income, and workplace), support networks, (family and friends), lifestyle factors according to the milieu etc. Hence, all determining factors depicted by the disciplines can be either subsumed to SOS or IOS to the exception of those belonging to mental decision processes.

The relation between SOS and IOS is thought to be twofold. On the one hand, the components of the SOS are to some extent translated by the individuals into their IOS to form their behavior. For example, selected from the commercially available technologies there is a certain stock of available appliances in the households. On the other hand, there are feedback-loops from IOS to SOS. Changed demand on the individual level through change of expectations can induce changes on the SOS level, e.g., new products and services or change of market conditions.

The SOS and IOS encompass together the realm of potential determinants of ECB as well as its change. If these factors make up ECB, then they will also make up its change as we already argued above. It is not the factor *per se* that will change, but how it is instantiated today. Prices will always be determinants, but their variation leads to different behaviors. The task consists in looking at those variations that will lead to the expected change of behavior. Moreover and as expressed by the notion "opportunity," it is neither the case that every single contextual factor is a necessary prerequisite in explaining the observable ECB nor is the listing of the factors in the graph meant as being exhaustive.

Decision-Making

Given their social and IOS, individuals make specific decisions "translating" the elements within the OS into a specific observable material- or action-specific ECB. Hence, besides the factors within the OS, there are additionally those factors that are determinants for "decision-making." As described in Sections "ECB and its Change from a Psychological Perspective" and "ECB and its Change from Consumer Behavior Perspective" above, these are belief structures, value systems, attitudes, emotions, motivations, heuristics, and biases. For example, demands for comfort, motivations like financial benefits, or environmentally friendly values and emotions could translate the OS-factors into behavior X, whereas other determinants for decision-making could lead to behavior Y. Thereby, we let "decision-making" encompass both – conscious choices as well as routines, as long as the latter implicitly includes the option for choices. Together with SOS and IOS, this leads us to **Figure 4** as the overall scheme for explanantia (where choices and routines are of course not themselves explanantia but placeholders for linking the explanantia to the explanandum).

That scheme of explanantia is meant to function as a heuristic help sort the complexity of potential explaining factors. It is not to be confused with a sequenced model or theory, as we already pointed out above. No causal claims have been linked to the factors within SOS and IOS and the factors for decision-making. Causal claims have to be empirically established. We expect that the according evidence on how the different factors in and between the three different dimensions (SOS, IOS, and DM) "play" together will lead to a better understanding of what determines ECB and its change. For example, constraints in the SOS might be so severe as to make it extremely costly for an individual to act on his/her values

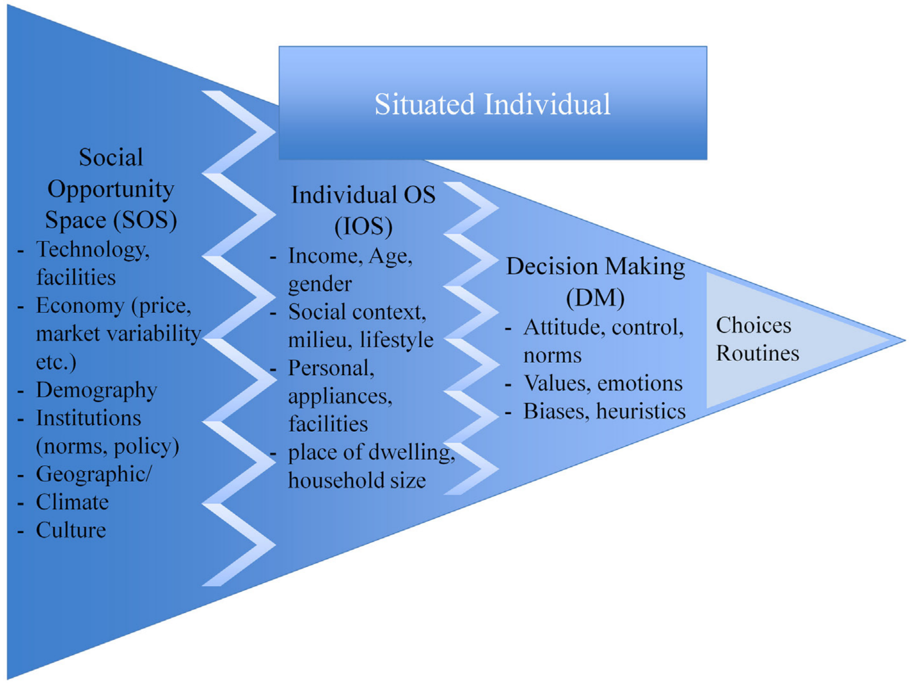

FIGURE 4 | **Explanantia – determinants of ECB and its change**.

or to react to price incentives. Similarly, the individuals' value system might determine how they react to common behavioral economic incentives. For example, in the U.S., conservatives have been found to be substantially less responsive to environmental nudges than liberals (Costa and Kahn, 2013). A similar effect might explain why individuals react so differently to the very same economic incentive to invest in home improvements (Stern, 1986, 2014). Thus, by starting to look into how these different dimensions interact, we expect to get a more comprehensive explanation of ECB and its changes. Finally, the relevance and impact of social segmentations need to be scrutinized.

Segmentation of Individuals

Social segmentation of individuals and the related lifestyles are an important field of research especially emphasized above by several disciplines, including business science and consumer behavior (market segmentations) and sociology (social structuration, milieus). Darnton (2008) also emphasized that analyzing ECB should include social structuration and not go along an abstract type of consumer (everyman-models). Although, there is so far only a small amount of studies in the field of ECB using social segmentation as an additional explanatory category, those who go along it reveal interesting insights (e.g., Spaargaren, 2003; Barr and Gilg, 2006; Jetzkowitz et al., 2007; Sütterlin et al., 2011). The argument given in favor of including social segmentation as an analytical category often consists in claiming that individuals from different socially segmented groups have different sensitivities toward steering instruments, products, and services. Knowing the ECB within different social segments would, as the argument goes, improve the capacity for steering. It would allow providing tailor-made instruments or services.

We leave it an open question here, whether social segmentation is an additional explanatory category to our scheme or whether social segmentations basically represent clusters based on combinations of the different factors set up by our scheme. There is not enough space here to enter the according debate on methods and approaches that capture social segmentation (e.g., inductive on specific domains or deductive on the society as a whole), and it is fairly doubtful whether this can be done without further theoretical investments. Given the assumed importance of social segmentation and related lifestyles, however, it should be explicitly taken account of when addressing ECB and its change.

Governance of Individual Behavior Patterns

The third component of our framework deals with the governance of individual behavior, following question (5). "Governance" is not just another word for "policy" but refers to constellations of instruments, institutions, and actors that collectively shape individual action toward common goals (cf. Section "Governance of ECB from a Political Science Perspective"). "Governance of ECB" potentially includes all three dimensions politics, polity, and policy (cf. Section "Governance of ECB from a Political Science Perspective"). Drawing on this and in light of the differentiated picture of ECB as well as the multiple factors that explain the various types of behavior and their changes, governance of ECB turns out to be a complex issue itself. It is not merely about the proper design of single policy instruments addressing particular factors. Rather, governance is about the design of complex instrumental arrangements that address different factors in a coordinated way. These instrumental arrangements are themselves created and enacted by institutionally embedded collective actors (i.e., not only the state but also business and civil society) affecting the design and implementation of instruments as well as their legitimacy and effectiveness. Questions to be answered then include: who (what constellation of actors) is governing, under which conditions (institutional setting) with what means (set of policy instruments) to address which determining factors of which type of individual energy-related behavior? These basic questions can orient both the empirical analysis of existing governance arrangements and the design of practical governance arrangements. In **Figure 5** accordingly, the three domains policy, politics, and polity frame the triangle, taking account of policies, procedural factors such as networks, hierarchies, resources, and structural factors like institutional settings. The arrows above the triangle link the governance scheme to the scheme of determinants (SOS, IOS, and decision making).

The general three-dimensional conception of governance can be further specified by including the characteristics (a) group-specific; (b) multi-factorial; (c) integrated; and (d) adaptive:

(a) group-specificity: governance of ECB can address diverse groups of individuals: different individuals with different behavior patterns, not acting constantly rational or consistent. Moreover, there are different types of ECB. By analyzing or designing governance of ECB, the potential relevance of group-specific factors or the characteristics of different ECB-types need to be considered.

(b) multi-factorial: governance interventions can be directed to different components of the opportunity space or decision-making (access points). For example, one could try modifying market conditions or legal norms (arrow to the SOS) or to directly influence the ECB by a change of price structures (arrow to the IOS). Likewise, factors such as heuristics behind decisions or routines could be addressed, say by interventions like nudges, or information campaigns. Thus, interventions can trigger a number of factors. However, not all factors that explain ECB and its change are potential access points for governance, e.g., demography, geography, age, or gender.

(c) integrated: additionally and related to (b), there are multi-instrumental settings (policy mixes), accompanied by interactions between the different instruments. The according analysis (or design) of policy instruments on change of behavior then should not only address sets but also combinations of instruments and their coordination by taking their aggregated effects into account.

(d) adaptive: current patterns of ECB are the result of a certain incumbent governance regime and changing ECB requires its transformation. As individual behavior can only be changed step by step and as attempts of governing energy-related behavior are embedded in complex societal situations that include many options for unexpected development and side effects, governance of change is like an ongoing task. Analytically, it requires including uncertainty and the capacities for on-going adaptive forms of governance.

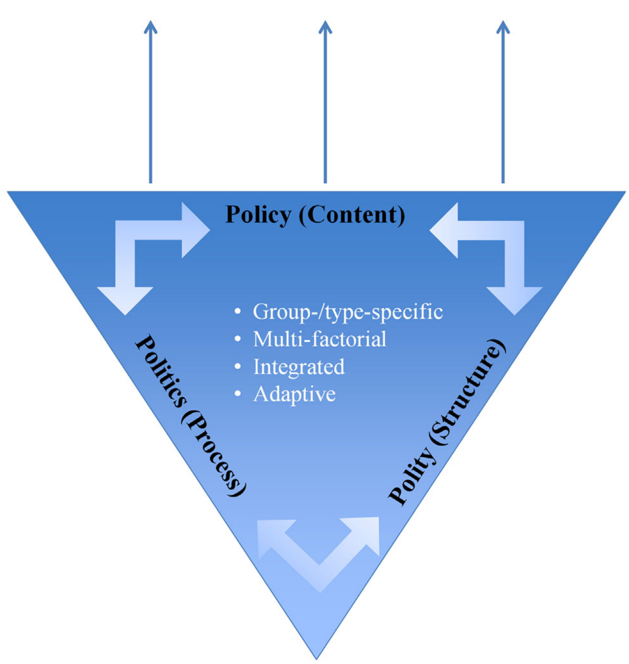

FIGURE 5 | **Governance of changing ECB.**

Put in a nutshell, "governance" offers a differentiated set of categories for analyzing the steering side of change of ECB. It directs the researcher to taking account of the different dimensions of governance, of different groups and types of behavior as well as the variety of explaining factors, and requirements of integration and adaptability. It provides a conceptual basis, which allows looking at which type of governance arrangements has the potential to influence which type of determinants to get which type of change of behavior. Which factors are really relevant in what fields of change of ECB has to be established empirically.

Besides, the question of desirability or legitimacy arises. The "bossy state" telling citizens how to behave or how to change behavior and leaving the individual with only restricted choices is rarely compatible with a liberal stand. Likewise, scientists can certainly not prescribe how individuals should live their lives. Is there something like a liberal paternalism expressed for example in nudging efforts? In any case, research on governance of change of behavior needs to be accompanied by scrutinizing the legitimacy of such governance.

Putting the three pieces together then, we come to the overall framework as illustrated in **Figure 6**.

Synthesis and Outlook

The framework displays our answers to the five initially stated questions and links the three analytical aspects (explananda, explanantia, and governance). It systematically distinguishes the two explanatory perspectives and offers an integrated approach to understand and explain ECB and its (governed) change. Based on the best available disciplinary and interdisciplinary knowledge and aggregated over the different subsectors of consumption, our framework provides an interdisciplinary basis for linking different aspects in empirical settings. The framework – not model or theory – does not offer explanations or evidence about sequenced relations. Moreover, we certainly do not claim that an empirical research design has to pay attention to all elements addressed by the framework. The framework

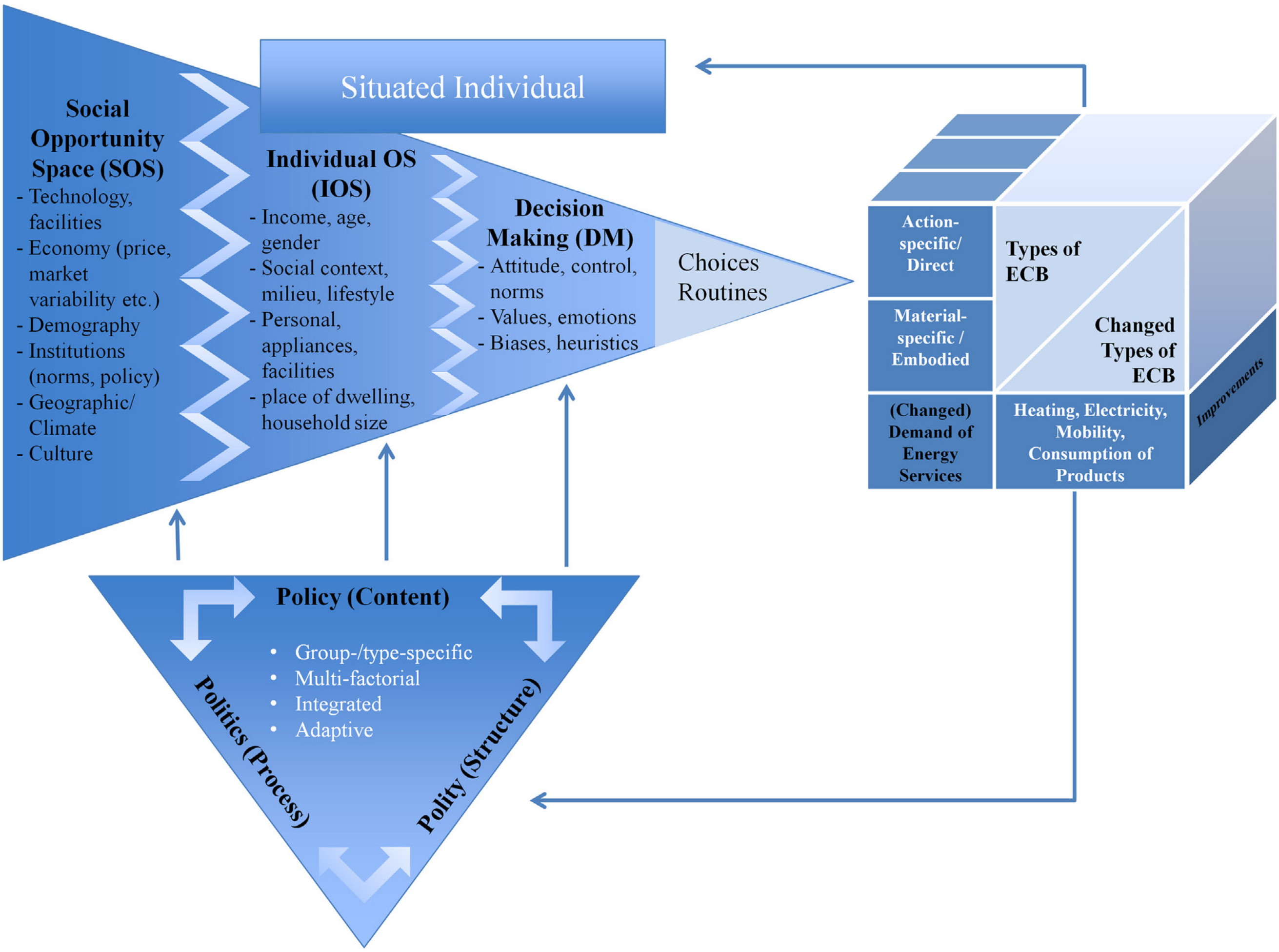

FIGURE 6 | **Integrated framework – understanding ECB and the governance of its change**.

is a heuristic tool to guide further theoretical work and empirical analyses by especially addressing possible interfaces between the manifold of factors. Particularly, we expect our framework to guide the research in our interdisciplinary research consortium within SCCER-CREST's, leading to concrete recommendations on governance of individual energy-related consumption behavior.

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